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Patrice Desvallées, Nicolas Bérend, Marie-Christine Bernelin, Marc Valès,
Christophe Chavagnac, Jean-Philippe Dutheil ArianeGroup

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AT CROSSROADS OF AERONAUTICS & SPACE: WHAT MATTERS FOR AEROSPACE VEHICLES FEATURING ULTRA-HIGH PERFORMANCE

Patrice Desvallées

Direction Générale de l'Aviation Civile (DGAC), France, patrice.desvallees@aviation-civile.gouv.fr

Nicolas Bérend

ONERA, the French Aerospace Lab, France, nicolas.berend@onera.fr

Marie-Christine Bernelin

Dassault Aviation, France, marie-christine.bernelin@dassault-aviation.com

Marc Valès

Dassault Aviation, France, marie-christine.bernelin@dassault-aviation.com

Christophe Chavagnac

ArianeGroup, France, christophe.chavagnac@cnes.fr

Jean-Philippe Dutheil

ArianeGroup, France, jean-philippe.dutheil@ariane.group

Abstract

Making the best of both Earth very deep gravity well and thick atmosphere, the World's aerospace sector, be it civil-commercial or military, has managed to produce, especially since the World War II, a wide range of diverse ultra-high-performance flying systems. It now covers a wide range of domains, categories, programmes and concepts, including new emerging vehicles able to fly through the airspace and the atmosphere and/or in the outer space, back and forth. These projects range from aviation (subsonic, transonic, supersonic or even hypersonic planes) to suborbital and orbital systems. They include ultra-high performance aerospace vehicles, sounding rockets, and other emerging or innovative systems like high-altitude platforms (HAPS, airships, balloons, drones), suborbital aircraft systems (either for local A-to-A flights or for A-to-B 'near-orbital' ultra-fast Earth-to-Earth transport) up to multi-stage space launching systems. In order to better grasp how all these various systems and operations' types compare, complement and may interact with one another, main aerospace categories will be represented with respect to their altitudes, speeds as well as their embedded energies, in a pedagogical way. As such, the big picture will be provided together with a sense of scales. It also helps to trace potential articulation or gateways between aviation and space. Despite the absence, in conventional or customary international laws, of an explicit altitude delimitation between national sovereign airspaces and outer space, this paper will show that the anchoring physical limit for ranking these advanced systems is rather more a matter of embedded energy than altitude or speed alone.

Keywords: Aerospace, systems, suborbital, near-orbital, HAPS, stratospheric, sounding rockets, high-altitude, high-performance, velocity, embedded energy, airspace, Outer space, LEO, MEO, GTO, GEO.

Acronyms:

AMSL : Above Mean Sea Level (Altitude)
Ee : Embedded mechanical energy
E2E : Earth-to-Earth transport (A2B, or P2P)
FAI : *Fédération Aéronautique Internationale*
FL : Flight Level
GEO : Geostationary Orbit
GTO : Geostationary Transfer Orbit
HAPS : High Altitude Platform Systems/ Stations
HST : Hypersonic Transport
ICBM : InterContinental Ballistic Missile
ISS : International Space Station

LEO : Low Earth Orbit
MECO : (Booster) Main Engine Cut-Off
MEO : Medium Earth Orbit
SBT : Subsonic Transport
SD : Stardust capsule
SS2 : SpaceShipTwo
SST : Supersonic Transport
STS : Space Transportation System
TPS : Thermal Protection System
UTA : Upper Traffic Area
VSH : *Véhicule Suborbital Habité*

1. Introduction

The objective is to provide a better understanding of various aerospace systems and categories and how they could relate to one another. Main categories of aircraft and aerospace systems were thus represented on a single graph, in order to grasp the ‘Big picture’ as well as the challenge in designing ultra-high performance vehicles, given Earth’s very deep gravity well and thick atmosphere. This also helps to raise general awareness of potential thresholds, limits, ceilings, corridors, gateways and interface (e.g. between aviation and space) from the ground floor up to 36 000 kilometres altitude.

The initial idea back in 2019, was to display in a single logarithmic scale graph, the main aerospace systems ordered w.r.t. their altitude and speed plotted at their max ‘Embedded mechanical energy’ level (kinetic + potential energies / mass) during a nominal typical operation. Then, while building this graph, many elements were added along the way. Many links and thresholds were thus created and notably the key metric of ‘Embedded energy’ (Ee) that links both speed and altitude, and can help to better rank technological characteristics related to the design of these systems. (E.g. thermal protection, potential gate to characterize in-orbit space objects, etc.)

The introduction of the ‘Embedded energy’ metric, in addition to all the other information already displayed on the graph, was key and naturally delimited a number of areas, which finally led to a much more interesting, inspiring and complete global picture than initially envisaged.

2. Graph designing

The starting point was to choose the right scales for the graph X and Y axes. Linear scales were not really appropriate, as ranges for speed/velocity and altitude, are too large. Logarithmic scales were thus preferred for getting a meaningful overview of all possible aerospace systems in the same graph, from the ground (sea level) up to the geostationary orbit (GEO ~35,800 km) altitude and, concerning the speed scale up to 100,000 km/h (~28 km/second).

The ‘Above mean sea level’ (AMSL) is the reference chosen for the altitude and the horizontal cruise speed for airplanes, or apogee velocity for near or in-orbit systems is computed (for example the A-to-A suborbital systems that are not designed for cruise are represented with their apogee speed which is close to zero – see section 4.5 below). Moreover, to compute speeds of circular orbits, the velocity needed to compensate the centrifugal force is figured as well:

$$v = \sqrt{\frac{\mu}{r}} \quad (1)$$

With:

- μ : Earth standard gravitational parameter

- r : altitude referred to the center of Earth

Some popular references were also added in order to grasp more easily the sense of these [altitude/speed] values. For example, altitude of the Everest (8849 meters), velocity of a rifle bullet (~1.3 km/s), but also the Karman Line (100 km altitude) which is the FAI (*Fédération Aéronautique Internationale*) non-official, but often used, altitude known as an informal boundary between airspace and Outer space.

The Stratosphere ceiling, roughly at 50 kilometers altitude (B), is sketched: it also corresponds to the maximum theoretical buoyancy altitude for stratospheric balloons, with only 1% of the ground pressure (Po) remaining. Moreover, the Sun escape velocity from Earth (42.1 km/s) is added:

$$v = \sqrt{\frac{2\mu_{\odot}}{r}} \quad (2)$$

With:

- μ_{\odot} Sun standard gravitational parameter

In order to provide a clear working basis, other information is recorded:

- Ambient pressure decrease, linked to the altitude through a negative exponential,
- Iso-Mach curves vary with altitude w.r.t local thermodynamics conditions (see figure below),
- Hypoxia phenomena for human beings (lack of oxygen) may happen as low as 3 km altitude,
- The Armstrong's limit at around 19 km of altitude, above which atmospheric pressure is so low (~6% x Po) that water (and blood) boils at the temperature of the human body (37°C),
- Magnetopause, the boundary between the planet’s magnetic field and the solar wind.

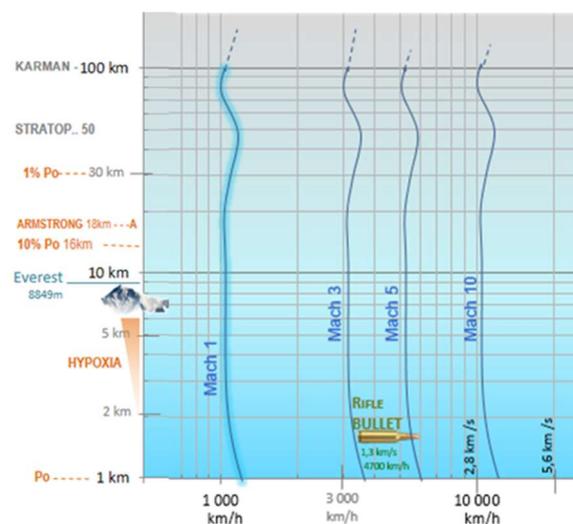


Fig. 1: Base of the Graph 1.0

Finally, some useful delimitations for satellites are figured:

- LEO, between 155 and 2,000 km,
- MEO, between 2,000 and 35,800 km,
- GEO, at around 36 000 km,
- Van Allen inner belt, an energetic zone charged by particles from the solar wind. This belt traps some energetic electrons and protons. For example, this belt is the origin of polar auroras (also known as “northern/ southern lights”).

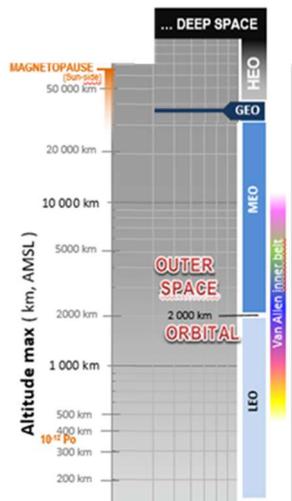


Fig. 2: Base of the Graph 2.0 (HEO: High Earth Orbit)

3. Embedded energy and graph areas

Before positioning the main aerospace categories and systems on the diagram, the large ranges of altitude and speed allow to determine some specific areas and curves. Some areas will be based on the ‘Embedded energy’ (E_e), or specific energy. E_e is the mechanical energy of an object (kinetic + potential energies) divided by its mass:

$$E_e = \frac{E_c}{m} + \frac{E_p}{m} = \frac{V^2}{2} - \frac{\mu}{r} + C \quad (3)$$

With:

- E_c : kinetic energy, in Joules (J)
- E_p : potential energy, in Joules
- m : mass, in kg,
- V : speed, in m/s,
- C : constant corresponding to a 0 potential energy reference at ground level ($r = 6,371\text{km}$)
 $C = 62\,560\,988 \text{ (m}^2/\text{s}^2)$

‘ E_e ’ is a meaningful key metric as it remains constant for example during ballistic trajectories and any circular or eccentric orbits (with no or very little atmospheric drag).

Each system on the graph is plotted at its highest ‘Embedded energy’ level reached during a typical nominal operation. The following table gives the

average Max- E_e values for main aerospace systems and categories:

Aerospace system/ category	Embedded energy ‘ E_e ’ (Joule/kg)
Robin DR400	~48 kJ/kg
ATR72-600	~86 kJ/kg
Airbus A320neo	~145 kJ/kg
Airbus A350	~160 kJ/kg
Dassault Aviation Falcon 7X	~172 kJ/kg
HAPS	~147 to 245 kJ/kg
Concorde SST	~354 kJ/kg
Local suborbital (Alt.85km)	824 kJ/kg
Local suborbital (Alt.110km)	1 062 kJ/kg
TPS curve (C* curve)	1 100 kJ/kg
Sounding rocket (e.g.600km)	5 385 kJ/kg
Earth-to-Earth suborbital (Paris→Atlanta, ~30 min)	~28,0 MJ/kg
Earth-to-Earth suborbital (Paris→Sydney, ~49 min)	~31,0 MJ/kg
Lowest Earth Orbit (A*, O*)	32,0 MJ/kg
Highest LEO (2000km)	38,7 MJ/kg
GTO (630km↔35800km)	54,5 MJ/kg
GALILEO (23830km, MEO)	55,8 MJ/kg
GEO (~ 35800km)	57,8 MJ/kg
Earth-to-Moon (Apollo)	~62,0 MJ/kg
Earth-to-Mars (Mars-2020)	~70 to 100 MJ/kg

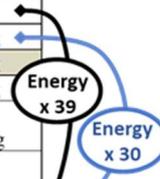


Fig. 3: Max- E_e values of various aerospace systems (* Ref. A, C, O: see below).

Every pair of [altitude; speed] data may be converted into a single value of embedded energy and, when choosing a value of E_e , constant (iso-) Embedded energy curves may be derived accordingly. That is exactly what has been done for example with the 1100 kJ/kg, 10 MJ/kg, 32 MJ/kg, 40 or 54 MJ/kg iso- E_e curves. If the highest embedded energy of a nominal operation is greater than 1100 kJ/kg, the aircraft or aerospace vehicle above this energy level is very likely to require a Thermal Protection System (TPS) in order to survive (re-entry) heating (unless it uses spare/residual onboard propellant or energy to reduce its velocity prior to re-entry). The associated iso- E_e line at 1,1 MJ/kg is labelled ‘curve C’.

Concerning the 32 MJ/kg threshold, the iso- E_e curve labelled ‘O’ represents the minimal embedded energy needed for a passive object to be orbital.

After having traced and positioned these initial thresholds, curves and areas, some important reference points such as point ‘A’, also at $E_e = 32 \text{ MJ/kg}$, are drawn. This is the lowest stable passive (non-propelled) circular Earth orbit, at around 155 km of altitude with an orbital velocity of 7.81 km/s. ‘A’ is the lowest point of the ‘O’ curve (including various orbital eccentricities, see Fig.4) and of the ‘Oc’ curve (Oc: envelope of circular Earth orbits).

‘A’ represents the so-called “lowest stable Earth orbit” because a non-propelled circular satellite at 155km of altitude or lower, quickly experiences a

significant orbital decay. The atmospheric drag will pull it in. It would only perform a few 88-minutes orbits around the Earth before being progressively slowed down by local atmosphere's derived drag (low pressure and high speed), losing altitude, and thus, facing the even greater drag of the denser lower layers of the atmosphere.

To better grasp the orders of magnitude w.r.t. orbital decay of space objects, a window 'H' is indicated: average duration for circular orbit decays as a function of initial orbiting altitude of a non-propelled space object. Starting from the A point, the possible in-orbit trajectories are figured, and then the envelope of Earth circular orbits (curve Oc) is derived accordingly. Finally a Geostationary Transfer Orbit (GTO) dubbed 'G', which correspond to the path of an elliptical orbit with an apogee at [35,800 km altitude and 1.64 km/s speed] and a perigee at [630 km altitude and 9.88 km/s speed]. The embedded energy (Ee) corresponding to this GTO trajectory is constant at 54,5 MJ/kg. While computing embedded energy, more than six curves, thresholds and areas, to be as accurate as possible, have already been indicated for various aerospace systems categories.

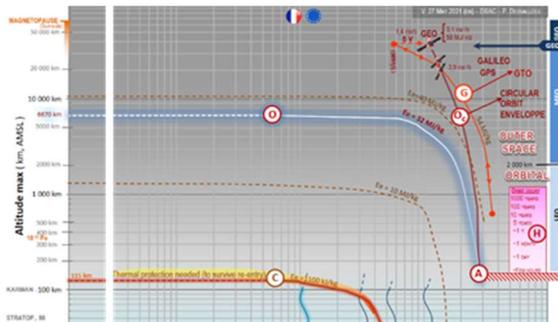


Fig. 4: Areas delimitations 1.0

Last but not least, in order to reach an homogeneous level of consistency and accuracy everywhere on the diagram, some additional zones and markings are figured:

- B: line at 50km altitude that indicates the maximum theoretical buoyancy altitude for Lighter-than-Air Aircraft (e.g. balloons),
- D: Flight Level FL660 (~20km altitude), represents the Upper the Traffic Area (UTA, controlled airspace) ceiling in most European airspaces,
- E: Cargo-Dragon capsule on Falcon9 launch trajectory to the ISS with the launcher max-Q (max aerodynamic pressure) and its booster Main Engine Cut-Off (MECO) indicated,
- F: re-entry, descent & landing of the American Space Shuttle (STS) with indication of the re-entry ionization zone (blackout and disruption of radiotelecommunications) lasting around 13

minutes, from an altitude of ~80km down to 55km in that case.

- I: circular orbital velocity at 155 km altitude and 7.81 km/s (equivalent to ~ Mach 24) speed,
- T: Telecommunication blackout zone due to re-entry ionization and heating,
- L: Escape velocity from Earth at 100 km altitude, which corresponds to 11.3 km/s.
- Asteroids re-entry velocity are also represented: they usually range from 72km/sec down to 12km/sec for the slowest meteors.

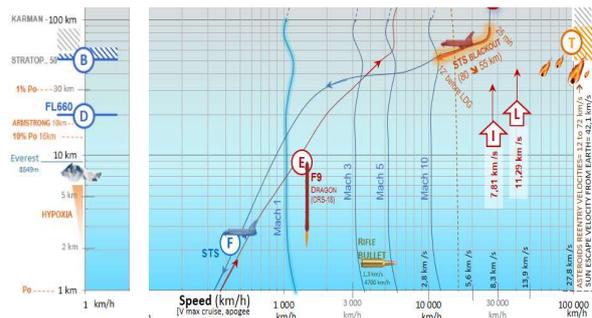


Fig. 5: Areas delimitations 2.0

4. Main categories of aerospace systems

With an accurate graph, which covers very large ranges of altitudes and speeds, it now is possible to position the various aerospace systems and categories in the diagram, represented (to scale) with a color code (Green: military aircraft, Blue: civil aircraft, Purple: other aerospace systems, Red: spacecraft):



Fig. 6: graph legend

1.1. HAPS category

The HAPS category includes slow and light stratospheric unmanned aircraft systems, such as weather or scientific Helium-balloons, operated for many decades in the stratosphere (e.g. CNES, since 1962). HAPS also covers a few new concepts and projects of long duration slow and light drones, airships or balloons, with various purposes like study the stratosphere, provide surveillance, telecommunication relay (broadband internet) or remote sensing. The HAPS category is mostly in the [0: 120km/h] speed range and [18: 30km] altitude range. Today some HAPS projects are being researched and prototyped:

- *Lighter than air* (LTA) such as 'Strateole-2' (CNES) or 'Stratobus' (Thales Alenia Space);
- *Heavier-than-Air* (HTA) solar motorized gliders, such as 'Zephyr-S' (Airbus) or 'Sunlider' (HAPS Mobile) with a 78m span.

Besides, in the last few years, many HAPS projects have been terminated like the 'Loon project'

(Alphabet/ Google), the ‘Solaris-50’ (defunct ‘Titan Aerospace’) or the abandoned ‘Aquila’ project (Facebook), etc.

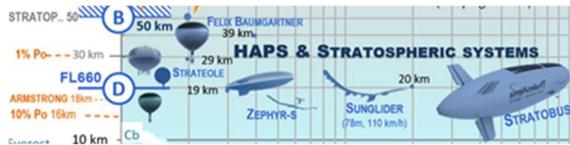


Fig. 7: HAPS category

4.2 Subsonic Air transport (SBT) category

The SBT subsonic aviation category is in a medium speed/altitude area with sufficient atmosphere density to benefit from enough lift, with relatively low drag and no need for thermal protection. It features the best cost/range ratio for any point-to-point operations. The main aviation industry has successfully and safely developed in this subsonic area. Thanks to the most recent and efficient aeronautics technologies, the graph highlights a trend to cruise higher and faster, thanks to state-of-the-art lighter aerostructures and very efficient engines and equipment, illustrated with the Airbus A320neo, A350 modern airliner or Dassault Aviation Falcon business aircraft families.



Fig. 8: Dassault Aviation Falcon 7X, Airbus A350

This SBT category includes several aircraft types (as long as their speeds do not exceed Mach 1): airliners, business jets, turboprop aircraft, general aviation and helicopters such as the highly efficient ATR42 or H-160. The SBT altitude range is roughly [5: 16 km] and speed [200: 950 km/h].



Fig. 9: SBT category

4.3 SST (Supersonic) Category

The Concorde Mach 2.02 supersonic aircraft, in service from 1976 to 2003, is the first and only supersonic airliner ever commercially operated.

Today, the Supersonic category (SST) includes mostly high-performance military jet fighters, like the recent ‘Rafale’. Jet Fighters were crucial during the Cold War, and some records still belong to these

aircraft. Their capability scope is within [15: 40 km] altitude & [1000: 3000 km/h] speed range. The graph highlights that these aircraft are getting closer to curve ‘C’ where vehicles start to experience some significant thermal effects on their aerostructures and systems. However, no full-fledge TPS is needed for this category.



Fig. 10: SST category

4.4 E2E suborbital category including “Near-orbital” systems

Earth-to-Earth ‘E2E’ (sometimes also called Point-to-Point ‘P2P’, or A-to-B ‘A2B’) reusable suborbital systems are hypersonic and ballistic for some phases of their flights. They could develop into a new domain in the future, as some E2E suborbital projects are presently envisaged. They are positioned below the ‘O’ curve, but are clearly above the ‘C’ curve and thus need a thorough thermal protection systems (TPS). They will also require some advanced space technologies in particular to adapt their flights for atmospheric re-entry and glide descent. They will need to use state-of-the-art technologies from both Aeronautics and Astronautics domains.

E2E suborbital systems could have trajectories similar to InterContinental Ballistic Missile (ICBM).

The ultra-long-range E2E suborbital projects which are aiming to go as far as halfway around the globe in less than 60 minutes (half Great Circle = 20,000 km, or 10,800 NM) could have apogee speeds close to orbital velocities (e.g. 7.2 up to 7.7 km/sec, right below velocity ‘I’ indicated on the diagram). This near-ubiquitous transport is then called “Near-orbital”.

The Starship-SuperHeavy space system presently developed by SpaceX in Boca Chica, South Texas, is expected to have in the future multiple derivatives for various purposes (e.g. crew and/or cargo/payloads to ISS, to Earth orbit, to the Moon or to Mars). So, the Starship family intends to cover various missions and purposes in the next decades, including a residual capability identified in 2017 by SpaceX which is E2E suborbital “Near-orbital” flights.

F.XX developed by Dassault Aviation is one example of such P2P suborbital projects.

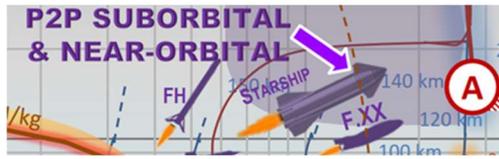


Fig.11: E2E suborbital & near orbital category.

The E2E suborbital category, like the local A-to-A one (see following section of this paper), has many sub-categories: landing & take-off modes, pilotage/control, propellant class, lift/drag ratio (lifting body, wings, flaps), etc. That is why, some aerospace manufacturers currently working on P2P suborbital project are trying to figure out which design or technology breakthroughs could be the most appropriate for the envisaged concept of operations.



Fig. 12: A2A and E2E suborbital trajectories.

4.5 Local 'A-to-A' suborbital category

The local A-to-A (or 'A2A') reusable suborbital systems (potentially carrying crew and/or paying passengers) differs a lot from other systems as their embedded energies are 30 to 39 times lower than the Ee of the lowest Earth Orbit (A=32 MJ/kg) or some Near-orbital E2E systems. The A-to-A suborbital speed at apogee is close to zero, compared to 6 to 7.7 km/sec for E2E flights.

Local A-to-A suborbital projects aiming at carrying human-tended experiments, astronauts, or even paying passengers, should not go higher than 115-120km in order not to cross the 'thermal protection curve' (C).

Also, they need much less speed, propellant and energy than E2E Near-orbital flights. After a vertical supersonic climb, they reach a 3-min ballistic weightlessness phase around their apogee before they progressively enter denser layers of the atmosphere.

Some examples of A-to-A suborbital programmes: 'NewShepard' of Blue Origin, 'SpaceShipTwo' (SS2) of Virgin Galactic, 'SpacePlane' of Airbus, and 'VSH' of Dassault Aviation.

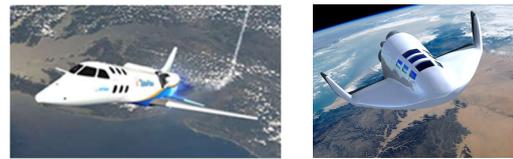


Fig. 13: New Shepard, SS2, Spaceplane and VSH.

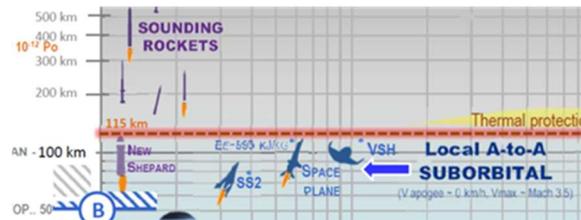


Fig. 14: A-to-A (local) suborbital category.

The sounding rockets category also has to be mentioned in this paragraph, as they technically also have local A-to-A suborbital trajectories. They can reach altitudes (e.g. 1,500 kilometres) much higher than the C curve (115km at zero apogee speed). However, they do not carry any occupants onboard, they burn on re-entry and thus can't be reused.

4.6 Launch-to-orbit and Return from orbit category

Due to the harshness of Outer space, orbital and space systems are probably the most technologically advanced projects. Also, due to Earth's deep gravity well and thick atmosphere, it's very hard to reach orbit, and single-stage-to-orbit (SSTO) from Earth is almost impossible today. For orbital systems aiming at re-entering, a thorough thermal protection system is needed, they transit through completely different areas and environments, with various flight conditions. They have to cross both the 'C' curve (1100 kJ/kg) and the 32 MJ/kg curve (O) to go to orbit or return to Earth.

Reusable orbital systems may also have in the future some derived versions used for E2E trajectories (e.g. Starship) or an easier access to space.

The US Space Shuttle program (STS) was a remarkable feat back in 1981 (maiden flight) but it took long time to refurbish between flights, it was very expensive to operate and experienced some fatal accidents. Since then, it remains a real challenge to develop a future quickly reusable human spacecraft able to return from orbit with reliability and safety levels much better than those observed for the Space shuttle (~10⁻² catastrophic failures per mission, U.S. human spaceflight history, orbital and suborbital, Ref. IAC-13-D5.1.4, 2013).

The orbital systems require some high-performance multi-stage configurations to be able to launch vehicles or payloads to orbit. Besides, once inserted in orbit, spacecraft need long lifetimes which is essential for their mission (e.g. telecommunication, broadband internet, remote sensing, positioning and navigation



Fig. 18: the hypersonic suborbital X-15 in the 1960s (max 96km altitude), from defunct North American.

Each of the two (A2A & E2E) suborbital markets could either emerge and dry-up (Niche markets), or develop in the next decades. In that case, issues of airspace disruption and safety could grow significantly.

Other important aspects include: Legal and regulatory issues, safety of vehicles, crew and paying passengers, as well as third Parties.

Also, societal acceptance, medical issues, National Security and sovereignty, types of propulsion and energies, energy sobriety, environmental impact and sustainability, security (e.g. cyber threats), costs and technology readiness are other key issues.

Today, most suborbital projects still need R&D to mature further. In a timely manner, a future Safety regulatory framework should be well-adapted to the most promising & mature technologies.

Legal options (Air Law, national Space Laws, hybrid Air/Space or *sui generis* law) and safety regulatory frameworks would then have to be adapted to future suborbital systems, as they will mature. In Europe, industry and national and E.U. rulemaking organizations started preparatory work on higher airspace operations, including research and pre-development in detailing how to best design-to-safety these new ultra-high performance machines and how to accommodate them safely into the airspace.

Before starting any commercial flights with paying passengers onboard, suborbital systems will need to mature and gain sufficient experience to prove their safety. Otherwise, the first catastrophic failure (killing onboard High-Fare passengers) is likely to jeopardize this pioneering industry for many decades.

In order to accompanying industry innovation while preventing such daredevils' catastrophic consequence, passengers, public and third parties need to be *ab initio* well protected, with a timely, flexible and well-suited system certification and safety regulatory framework.

6. Conclusion

By building this [Altitude, Velocity] (and Embedded energy metric) graph from the ground up to 36,000 km of altitude, comprehensive information and concepts linked to Aeronautics and Astronautics sciences are figured. The anchoring physical limit for ranking the aerospace systems is a matter of embedded energy, rather than speed or altitude alone. Main aerospace categories are identified together with

thresholds, limits and potential interfaces, corridors or gateways between Aviation and Space.

Making the best of Earth's deep gravity well and thick atmosphere:

- Today, only ultra-high performance aerospace systems are able to fly very high or very fast;
- It is even harder to fly both very high and ultra-fast so as to reach an orbital embedded energy (32 MJ/kg);
- Local A-to-A suborbital operations, with either 85km or 110km apogees, are much less technology-demanding, as they are 39 or 30 times less energetic than the lowest circular Earth orbit (~155 km) or suborbital launches to near-orbit (E2E);
- Once in Orbit or Near-Orbit, re-entering and landing back safely on Earth is very challenging (especially for human-rated flights carrying crew and/or passengers);
- Staging is necessary for launching to orbit;
- Today, Single-stage-to-orbit (SSTO) or Single-stage-to-near-orbit operations (E2E, SSTNO) – with significant payload - are quite unlikely from Earth.

While optimizing the design of future ultra-high performance aerospace projects, the industry has to push the envelope and use the most-advanced technologies available. Also, there are interrelated and recursive factors w.r.t Max-Embedded energy (E_e), speed & altitude targets, onboard energy or mass. For example, in order to increase the design Max- E_e by say +1%, then, larger cryo-tanks, additional thrust, stronger TPS and heavier aerostuctures have to be designed, and more energy and propellant will in turn be needed to cope with the added equipment, energy and mass. In the end, most key parameters would likely change quite significantly, way beyond the initial 1%.

Going close to the edge on margins on various parameters while iterating the design quickly, makes it even more challenging to reach acceptable reliability and safety levels for the entire system.

When pioneering a new domain, it can take many years or decades to reach safe, technology-proven and socially acceptable designs.

Similarly, while designing and prototyping a HAPS aircraft system project, there is a recursive factor to mass and a trend to get bigger, heavier and fly lower than initially expected. This trend has already been observed for some recently defunct HAPS balloon project, aiming initially to operate between [FL600-FL900] but, in the end, was only able to reach much lower levels [FL500-FL650] (some military and business jets fly well above FL500). Also, some

balloons uncontrolled descents leading to dangerous situations have been reported several times by Authorities in various FIRs around the World.

Similar graphs with thresholds and gateways, can be drawn for other planets or moons, with various gravities and atmospheres, like **Mars** or **Venus**.

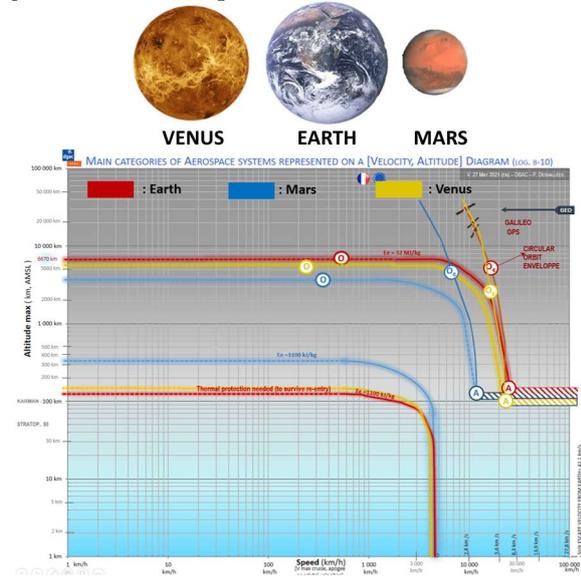


Fig. 19: comparison of the main thresholds between Earth (red curves), Mars (blue) and Venus (yellow).

Today, the available cutting-edge state-of-the-art technologies (e.g. Energy, propulsion, systems, materials, etc.) should allow new types of reusable ultra-high performance aerospace systems to be developed and to operate at crossroads of aviation and space. That is why this global diagram describing these systems is very useful in order to grasp what “At crossroads of Aeronautics & Space” truly means.

Finally, the ambition of the authors in making this chart widely available was also to have a kind of stand-alone tool, a “Big Picture” (see Fig. 20 below) that could help all private or public stakeholders interested in ultra-high performance aerospace systems in better understanding challenges at stake.

Acknowledgements

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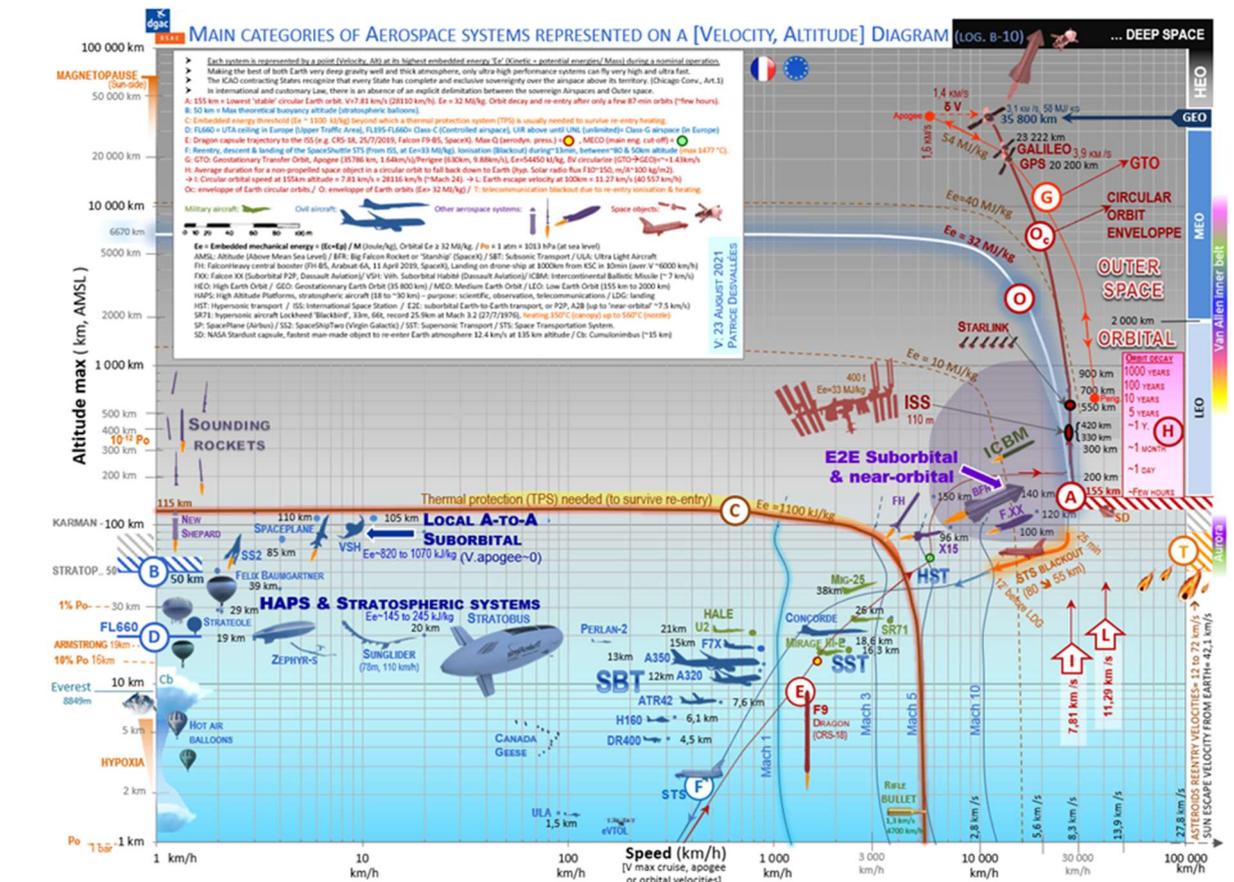


Fig.20: [Altitude, Velocity] logarithmic diagram of main aerospace categories, from the ground up to 36,000 km altitude. (Ref.: DGAC, Patrice Desvallées, 23 August 2021)