Global Space Exploration Conference (GLEX 2021), St Petersburg, Russian Federation, 14-18 June 2021.

GLEX-2021 – 6.1.1

Human spaceflight from Guiana Space Center

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Abstract

The use of Space has drastically evolved these last ten years. Tomorrow will see easier and cheaper access to Space, satellite servicing, in-orbit manufacturing, human private spaceflights to ever increasing number of Orbital Stations, road to the Moon, Asteroids, Mars. . .

It seems fundamental to make sure we can rely on robust, reliable, frequent and affordable access to and from LEO with both automatic systems and human missions; such systems are the bricks with which all the future operations in Space will be built.

Independent human access to space from Europe for our astronauts is a key to any future in Space.

It has been studied in depth since the 80's with Hermes Spaceplane, then through numerous studies, pre-development activities, and demonstrations such as ARD, X38-CRV or IXV, which now allow Europe to reconsider such an endeavor with a much higher confidence.

We have worked during one year on every aspect of a European Human spaceflight system aimed at being launched from Guiana Space Center. It would be a logical addition to new orbital infrastructures in LEO which, following the ISS retirement, are already under deployment by governments and commercial entities in the US, Russia, China, India. We found out that Europe could play a very specific role, deploying a “universal" vehicle capable to visit any future LEO architecture; following its historical tradition, Europe would be in a position to cooperate potentially with everyone in LEO!

We traded the various types of potential vehicles dealing with the recovery techniques for both nominal and abort cases. The launch with Ariane 6 has been looked at in detail and a particular effort has been devoted to the adaptation of the Guiana Space Centre.

A cautious examination of the required technologies shows that European industry is fully ready, and that most of these technologies are available. In particular, we have shown the readiness of Human-Rating systems, based on the ATV, Orion ESM and ISS pressurized modules.

Even if the capability requires a significant budget, the question is to know if Europe can be left aside in the future? Such a program would release a very strong positive sign for the young generations cradled with the feats of our astronauts; it would give motivating STEM objectives to the next generation of students.

As a major space power it is clearly strategic for Europe to develop independent human access to LEO in the current multipolar world.

Keywords: Human Space Flight, capsule, Guiana Space Center, European Spaceport

Acronyms/Abbreviations

ARD Atmospheric Reentry Demonstrator
ARV Advanced Reentry Vehicle
ATV Automated Transfer Vehicle
CLTV Cis-Lunar Transfer Vehicle
CRV Crew Return Vehicle
CSG Guiana Space Center
CTV Crew Transfer Vehicle
EAC European Astronaut Center
EAP Etage d’Accélération à Poudre
ELA4 Ensemble de Lancement Ariane #4
EPCU Ensemble de Préparation Charges Utiles
ESM European Service Module
ESR Equipped Solid Rocket

EVA	Extra-Vehicular Activity
IBDM	International Berthing/Docking Mechanism
IDSS	International Docking System Standard
ISS	International Space Station
IVA	Intra-Vehicular Activity
IXV	Intermediate eXperimental Vehicle
LAS	Launch Abort System
LEO	Low Earth Orbit
MTFF	Man-Tended Free Flyer
ROM	Rough Order of Magnitude
SME	Small & Medium Enterprise
SRB	Solid Rocket Booster
STEM	Science, Technology, Engineering, Mathematics
ULPM	Upper Liquid Propulsion Module
ZL4	Zone de Lancement #4

1. Introduction - Context

The questions associated to the possible human space launch from the European Space Port Guiana Space Center (CSG) cover a very wide range of domains…

What are the motivations, including political and societal ones? Why should we such topic be brought back on the table now? What could be the technical solutions, for the launcher side, for the inhabited vehicle, and for the ground installations? What are the required competences in Europe, and what is the associated technological availability? What would be the framework of such operations? Of course what are the associated costs and planning and how could one motivate such an initiative?

To answer all these questions, a dedicated informal Working Group met a dozen times in 2020 at the invitation of the CNES Launcher Directorate. This group was composed of experts in the domain, with a strong background and appropriate past experience, coming from Agencies (ESA Space Transportation Systems Directorate, ESA Human & Robotic Exploration Directorate, CNES Launcher Directorate, CNES Guiana Space Center), Industrials (ArianeGroup and Airbus Defence and Space) and external experts, former ESA astronaut and former CNES Director of Prospective.

The aim of this group was to identify a couple of credible scenarios, described from end-to-end, and to identify the necessary consolidation tasks to be performed in the short term to fully demonstrate feasibility. The results of this work could then be used as a skeleton for a discussion at European level.

Important note: the following chapters are only ideas potentially useful as a basis for future discussions, but they represent in no case a formal program proposal, and not even the formal position of the entities composing this Working Group. It is only a technical work that does not prejudge any programmatic desire to move towards an autonomous human flight.

2. Motivations

2.1 Future use of Low Earth Orbits

A major paradigm shift in space operations is currently taking place. We see numerous new actors, in addition to the traditional ones, institutional or private, with a clear desire to occupy space, for exploitation, exploration, security (both civilian and military) … The human spaceflight plays a fundamental role in these developments.

Low Earth Orbit can be seen as a future hub for space operations, as schematically depicted in figure 1. The number of potential applications initiated from LEO appears limitless:

- Servicing in orbit, orbital assembly, refueling, orbital transfer, inspections,
- Departure for Lunar, Mars or even more distant exploration missions, as well as return from these destinations,
- Departure for possible mining missions, and recovery zone for the returned material,
- Space Solar Stations, or Nuclear Waste Disposal, missions studied since the early 60’s which would benefit from a LEO hub,
- Departure zone for Planetary Protection missions,
- …

This LEO hub could then become the departure and storage zone for the “space tugs” and advanced “orbit transfer systems” aimed at servicing space. The announced end of the ISS operations opens the floor to numerous other multi-use orbital stations, or more generally a new LEO infrastructure, including for space tourism.

This concept of LEO hub raises the questions of its accessibility from ground, to and from; there shall be frequent, reliable, affordable, access to LEO infrastructure and return, both for cargo and human missions.

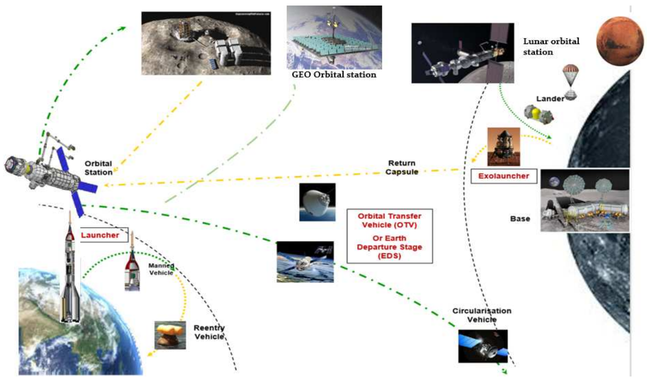

Fig. 1. Earth orbital environment structured per hubs

2.2 European autonomy in human spaceflight

Europe shall be present, guaranteeing an autonomous access to the LEO hub, and playing a major role in cooperative actions, as it is done today in the frame of ISS for instance, but including transportation missions. Otherwise, there is a strong risk that Europe will be marginalized as a 21st century space power.

The European astronauts currently benefit from a guaranteed access to space, thanks to international agreements, but these could evolve in the future with the emergence of private flights; as an example, as per today, 40% of the planned human flights with Space-X Dragon Crew concern private flights, on a commercial basis.

Europe shall complete its long term vision, in addition to its current mid-long term plans, in order to play at the same level as international partners in LEO and consolidate a seat at the international cooperation board when discussing LEO operations; only then Europe can be a major partner in the peaceful expansion of humanity in the 21st century. This can somehow appear highly questionable without an autonomous human spaceflight capacity, as is the case in Russia, US, China, soon India…

The inclusion of the European ambition in the totality of the "big picture" currently undergoing, exploration, orbital operations, future missions, consolidates the idea that LEO and Moon access is a prerequisite for a worthy contribution from Europe.

Access to the LEO "hub", both for cargo and inhabited missions, appears the minimal step to continue playing a role at international level.

2.3 A fundamental move for European citizens

One can note since several years now the very strong and positive reaction of citizens (taxpayers) to the flights of European astronauts. There is indeed a warm general reaction to the missions of the last recruited team of European astronauts (see figure 2), including at government level; in France the flights of Thomas Pesquet have been followed enthusiastically by every category of citizens, including young ones; it is exactly the same for the other countries involved, Italy, Germany, UK, Denmark, as was already seen during previous missions.

Fig. 2. European astronauts selected in 2009

We may believe that the current "story-telling" may be too weak, both at political and public level. Frequent remarks are "what is the use? Money could be used in a better way, …) and the roles of our astronauts are probably insufficiently explained in Europe, compared to US of Japan for instance. As an example, it is important to present Thomas Pesquet and his colleagues as a top notch scientist performing an incredibly large number of innovative experiments on board the ISS. Such justifications could lead to a strong support, if the "dream" aspect is associated.

The proposed initiative, if reasonable in terms of cost and planning, could generate a very strong general support, at political level, reinstating the rank of Europe, and at general public level, driving technological developments, innovations, startups, STEM vision, perspectives of exciting jobs, in very varied domains, for a long time… We like to compare with the vision that was given some decades ago with programs such as Airbus, Ariane, High Speed Rail, Channel Tunnel…

This is the right moment for Europe to revamp its strategic ambition, including both autonomy and sovereignty. Europe must be part of a "global horizon" that will drive industries, service companies, SMEs, in a general framework of international cooperation.

3. Possibilities of a multilateral approach

The Working Group analysed numerous possibilities of international cooperation, with a wide diversity of partners, both institutional and private. Europe can support very diverse models of partnerships.

We identified that there could be an interesting possibility of co-development of the capsule system with India, for instance with a capsule designed and developed jointly, launched both by Ariane 6 and by GSLV-MkIII.

The discussions on possible cooperation with USA showed some potential interest around a joint program based on the Dream-Chaser vehicle from Sierra Space, but several issues have to be clarified to enable such cooperation.

We devote extensive analyses on potential cooperation with Russia, but they did not lead to any credible scenario; technically the current Soyuz capsule would require significant modifications to cope with aborts in the middle of the Atlantic Ocean; we studied a joint development of the Orel system with the Russian part developing the capsule itself and the European part responsible for the Service and Propulsion Module, launched on Ariane 6 from Kourou and on Soyuz-5 from Russia, but this kind of scenario did not look feasible with level playing between partners, mainly considering export control rules.

We discussed on the possibilities of cooperation with our long lasting friends from Japan, but as far as can be noted, there are currently no sign at all of their potential interest in the domain.

Last we also looked at possibilities of cooperating with China on the joint development of a capsule system, but it did not appear credible considering the remarkable progress already made by our Chinese colleagues these last years.

4. A strong European experience

It is important to realize that despite the current lack of an autonomous human spaceflight capacity, Europe has acquired an impressive experience in the domain.

Numerous studies were performed in the past, such as Hermes of course, spaceplane stopped in 1993, but also X38-CRV (Crew Return Vehicle in the frame of ISS), stopped unilaterally by US in 2002, the ARD (Atmospheric Re-entry Demonstrator) which effectively flew in 1998; in depth studies such as CTV (Crew Transfer Vehicle) and ARV (Advanced Reusable Vehicle) must also be quoted.

An in-depth study was performed considering the potential use of Ariane 5 ME to the launch of Orion, as a potential back-up for LEO missions; more recently the possible launch of the Dream Chaser on Ariane 6 was also studied.

From this experience, and other developments, we can say that all the key technologies are available, and generally demonstrated, in Europe.

Consider for instance the inhabitable modules technologies: Columbus, more than 50% of the pressurized volume of ISS, Cygnus, Axiom, Lunar Gateway…, they all come from Thales Alenia Space in Torino, Italy.

The hot thermal protections, including very innovative designs, since Hermes (and before) come from ArianeGroup in Bordeaux, and have been demonstrated in flight in during the re-entry of the IXV (Intermediate eXperimental Vehicle which serves as the basis for the Space Rider currently developed by Avio) flown in 2015.

The orbital autonomy and rendezvous capacity has been demonstrated 5 times with the ATV mission (Automated Transfer Vehicle) developed by Airbus Defence and Space; this includes a demonstration of full autonomy during the 5th flight. ATV has been the first automated vehicle to perform a docking with the ISS.

Key elements such as the Support Module, derived from ATV, or Service Module, derived from the ESM developed by Airbus Defence and Space, are fully available, demonstrated, are being evolved for the Cis-Lunar Transfer Vehicle (CLTV) definition and will be fundamental in the frame of a capsule system development.

The solid propulsion potentially necessary for the LAS (Launch Abort System) is very well mastered in Europe, whatever the size, and will raise no specific problem.

The Working Group nevertheless identified that some technologies are not yet demonstrated in Europe, such as the space suit. But one shall then note that the only suit needed for the early years of operations is the IVA suit (Intravehicular Activity) which is quite simple, for instance derived from military jet aviation; EVA (Extra Vehicular Activity) may be developed later, if needed.

5. Technical trade-offs and selected solutions

A very wide range of solutions have been analysed; not all are presented here in depth for the sake of length of the paper, but they were rather comprehensive.

5.1 System level

At system level, we traded the architecture, with solutions based on capsules (as ARD, CTV, ARV…), lifting body (as X38, IXV, Space Rider, Dream Chaser) or winged body (as VIRO, Hermes). These systems may be conceived as fully reusable, or with expendable Service & Propulsion Modules.

One important element is the selection of the recovery strategy, both for nominal and contingency cases, with the associated recovery means; various systems were traded such as parachutes, parafoil, winged landing or return following air capture.

5.2 Sub-system level

The key functions were examined at sub-system, or even equipment level.

This was the case for the LAS which can be of pusher type, solid propelled (as was Hermes, or New Shepard), pusher liquid propelled (as Dragon Crew or Starliner), puller liquid or puller solid propelled (classical on Soyuz, Gaganyaan, Dream Chaser…).

In terms of propulsion, the need concerns the orbital transfer (as on ATV) and the Attitude Control System functions, including the rendezvous and collision avoidance needs.

Several landing "interfaces" were also traded, both for nominal and abort cases, such as wheels, skids, airbags, air-recovery…). We looked at the requirements in terms of floatation devices, should the system fall in the middle of the Ocean following a contingency.

5.3 Pre-selected solution

A technical choice based on a capsule system, simple and robust, was chosen as the reference for further studies. It is important to note here that this is of course not THE final choice which necessitates serious pre-development studies and trade-off, and the concept may very well evolve in the future; for instance, a lifting body system derived from the Space Rider appears promising as well.

The system would consist in a recoverable capsule, and a Service & Propulsion Module. There would be two versions of the same size vehicle, a cargo version first, which would be upgraded to an inhabited vehicle in a second time, as it was proposed in the ARV study by Astrium, now Airbus Defence & Space, in 2012, and of course as recently done by Space X. The general concept from ARV is presented in figure 3, as an example of typical solution.

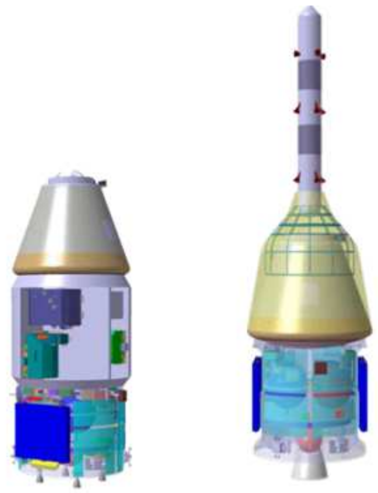

Fig. 3. Example of the ARV (Airbus D&S)

The Service & Propulsion Module would be closely derived from ATV, including its propulsion system, and ESM. Two variants are displayed on the figure, corresponding to different high level requirements.

The LAS could be a classical solid propelled puller, as on Shenzhou or Orion, in order to reduce development costs and risks It would include a control function enabling to land the capsule on its nominal landing site in case of abort. A complete detailed dimensioning of such a LAS was performed on Ariane 5 in 2009 and showed no significant criticality.

5.4 Launch system

The selected reference launcher is Ariane 6, our new workhorse, in its A64 version with 4 solid boosters ESR (Equipped Solid Rocket).

The detailed geometrical interfaces with the Ariane 6 upper stage still have to be studied, but a similar interface was already baselined on Ariane 5ME with no specific problem identified. The parallel between Ariane 6 and all the past studies led on Ariane 5 and Ariane 5ME show that such configuration is good. Figure 4 shows a past study done on Ariane 5, and recall the general configuration of Ariane 6, for comparison.

When looking in more details the comparison between the two launchers, we believe that the Ariane 6 configuration would even be safer than the one with Ariane 5.

The stages have separated tanks, lowering the risk of propellant mixture in case of anomaly. Some potentially critical points which raised concern on Ariane 5 are no longer present, such as the deployable nozzle of the upper stage engine Vinci.

Fig. 4. Ariane 5 (left) and Ariane 6 (right)

The robustness to an explosion of a Solid Rocket Booster is significantly improved, as the ESRs are monolithic, and much smaller than the Ariane 5 EAPs, leading to a "visibility" factor very reduced, i.e. a much lower probability of impacting the capsule.

There are numerous points, common to the two launchers, which have to be analysed, but all the detailed studies performed around the Vulcain propulsion system showed no major modification (still, additional redundancies required on electrical system, also on turbo-pump isolation, and so on…).

It is important to note the general safety approach applicable to the launch system. The reliability of the human version will be gained through the large number of cumulated flights in automatic version, taking also into account the Ariane 5 experience for applicable sub-systems. Then the safety of astronauts is addressed through the dimensioning of the LAS; the corresponding detailed study which was performed on Ariane 5ME for the launch of Orion is fully applicable. It can be noted that this overall strategy, high reliability, the safety addressed by the LAS is the one which was adopted on Falcon 9.

5.5 Preliminary trajectories

The preliminary trajectories, simulated by ArianeGroup, show no unfeasibility issues. On the opposite, they appear quite comfortable, as very similar to the ones flown for the ATV on Ariane 5. Figure 5 shows the typical flight profile, altitude versus distance to launch pad, to a circular 283 km x 51.6°.

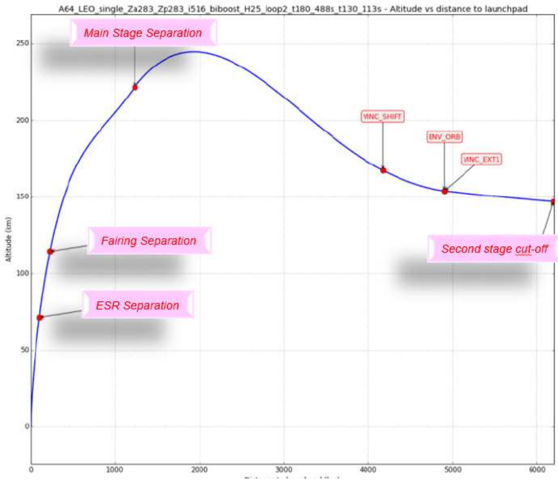

Fig. 5. Typical flight profile (ArianeGroup)

Figure 6 displays the typical flight trace, latitude versus longitude, for the same trajectory. Some key events are indicated such as T = 939 seconds, instant when the capsule impact point is no longer over the Ocean.

On such trajectory, the maximal acceleration is 4.5 g at the end of the ESR phase.

Simulations were done considering an aborted case every 50 seconds; the worst scenario leads to an acceleration level of 15.5 g during 5 seconds, which is considered as acceptable.

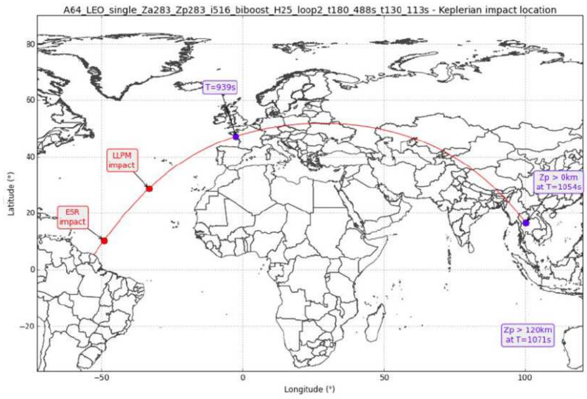

Fig. 6. Typical flight trace (ArianeGroup)

A simplified verification of the applied General Loads, i.e. mechanical dimensioning of the launcher, showed no problem.

The total performance in such configuration, on this orbit, is 21.9 tons which is ample enough; however, there are several performance improvement initiatives ongoing on Ariane 6, so such performance could most probably be increased by 600 kg or more. An Ariane 62 version could probably be sufficient.

6. Ground aspects in French Guiana

6.1 General map of the Guiana Space Center

Figure 7 gives a general view of the installations in the CSG (Guiana Space Center). On this map, one can notice the Crewed Flight Area in the South East of the zone and the nearby EPCU S5, Payload Preparation building which was built for the ATV. On the North West side, the ELA4 is the Ariane 6 Launch Zone, and just to the North, the Landing Zone for the Space Rider is also displayed, to be used also as the nominal landing zone for the crew vehicle.

6.2 Related installations in CSG

The general principle is of course to make maximum use of existing installations, benefiting mainly from the buildings developed for the ATV.

The Capsule and Service Module will be prepared and integrated in the EPCU S5 where no modification is expected, as the building is perfectly adapted. These integration activities are performed in parallel with the launcher campaign. The capsule assembly is then transported at the foot of Ariane 6 on the Launch Zone ZL4 on a dedicated trailer.

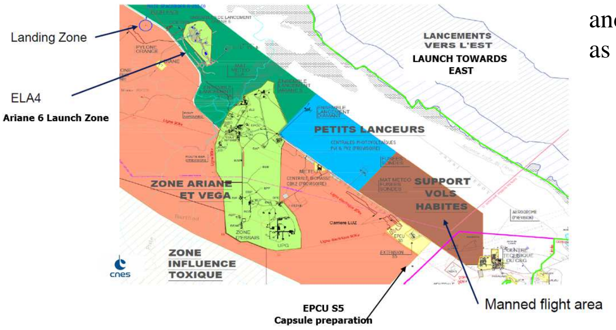

Fig. 7. Guiana Space Center (CNES)

The installation of the capsule system on top of the launcher is done thanks to the existing crane of the Mobile Gantry. The access to the capsule and Service Module is done thanks to the existing platforms; there could be a need to have an additional one, mobile.

The implementation of the Launch Abort System (LAS) is done at the latest time for safety reasons; it is also done thanks to the crane of the Mobile Gantry. One of the gantry platforms will probably have to be adapted in order to allow access to the interfaces between the LAS and the capsule.

6.3 Final Launch Chronology

The launch final chronology begins with the partial retraction of the gantry allowing the start of the launcher propellant fillings in a non-confined environment (Figure 8).

Fig.8. Partial retraction of the Mobile Gantry (CNES)

The access gateway is then installed between the mobile gantry and the capsule. Both stages of the launcher are filled.

The astronauts can then arrive on ELA4. They use the existing gantry lift to reach the platform (PF9bis) and they can enter the capsule using the access gateway, as shown in figure 9.

Fig.9. Access gateway for astronauts (CNES)

When the crew is in place and ready for liftoff, the access gateway is removed and the gantry is completely retracted. The access gateway is folded up along the front face of the gantry (figure 10).

After all the personnel have been evacuated from the launch area, the synchronized sequence can begin until launcher take-off.

Important note: as soon as the crew is in place, the LAS can be used, even with the mobile gantry partly retracted and with the access gateway deployed (some refurbishment may then be needed ☺).

Fig.10. Ready for launch (CNES)

6.4 Degraded case

In case of emergency evacuation, astronauts can use a rapid means of evacuation of "roller coaster" type, installed on the side of the mobile gantry (as displayed in figure 11). The astronauts can then reach a safety room located below the ZL4 massif (below the square plate of figure 12). This room will be protected and adapted accordingly. The crew will safely wait for the arrival of help to evacuate.

Fig.11. Means for rapid evacuation (CNES)

Fig.12. Access to the safety room (CNES)

6.5 ELA4 adaptations

The modifications of the ELA4 appear relatively limited and classical.

A telescopic and pivoting gateway is needed, to grant the access to the capsule from the mobile gantry.

A "roller coaster" type rapid evacuation system shall be created along the western facade of the mobile gantry.

Some additional platforms, mobile or fixed, may be necessary for access to the capsule, the service module and the LAS.

Some adaptation of the gantry retraction, and the gateway removal, shall be optimized in order to minimize the number of people in the ZL4 at the final phase of the launch chronology.

Some new dedicated on-ground interfaces specific to the capsule and the service module have to be created between the launcher and the umbilical mast.

Last, a fall back safety room has to be created for astronauts in the ZL4 massif.

It should be noted that these adaptations must be performed in parallel to Ariane 6 launch campaigns, so the planning of the associated activities may be a bit tricky.

7. A multi-destination system

One idea came rapidly within the Working Group, that of a "universal" system capable of visiting any existing or future infrastructure in LEO! Launching from Kourou has the major advantage that any orbital inclination can be reached (once verified the trajectory safety aspects).

The capsule would be equipped with a docking port based on the European Docking/Berthing system IBDM developed following the International Docking System Standard (IDSS). Such systems, shown in figure 13, are agreed by all major space agencies for future use.

Fig.13. European Docking/Berthing System (ESA)

This system is androgynous with contact force sensing and magnetic latching for capture; it enables a low impact docking.

This choice could place Europe at the centre of the LEO infrastructure. There would be evidence of a clear will to partner with everyone at international level, with visit to Russian, US, Chinese, Indian or private stations... There would be a strong potential for further evolutions of the capsule system, for instance leading to a small European Autonomous Station, in a way similar to a Man Tended Free Flyer (MTFF) kind of visitable module derived from Columbus; all the technologies are well mastered in Europe, and such a module could be co-orbiting with a larger station.

The capsule system could even be seen as a good answer to the very high demand currently for private (commercial) space flight.

Europe would cooperate with everyone!

8. Programmatic elements

8.1 Associated costs

The associated costs are under evaluation and cannot be presented here. There is of course a very large dispersion as there is no detailed concept yet.

Nevertheless, the numerous detailed evaluations performed in the past on Ariane 5 and Ariane 5ME give some elements upon which we can rely on. Typically, the adaptation of the Ariane 6 system is close to what was evaluated on the basis of Ariane 5ME; the adaptation of the ELA4 appears to present a relatively low cost; the Service-Propulsion Module is very close to what was already developed in the past, ATV and ESM, so there can be a good confidence in these costs; last the capsule itself is well understood, and its relative simplicity should allow to keep the development costs quite low.

An additional part appears much fuzzier, concerning the dedicated infrastructures in Kourou, the training centre, the recovery means… Its financial evaluation strongly depends on the needs, which are not yet expressed. Probably some of these developments could be performed in steps. However, obviously, these costs can be minimized considering the existing means, such as the European Astronauts Centre (ESA) in Cologne.

Let us just say here that the grand total would represent less than 2 € per year per European citizen in the concerned countries!

8.2 Typical planning

We believe that the total development can be led in less than 8 years.

It means that if a decision was taken at the 2022 Ministerial Conference to start a two years detailed study, and if the final development decision was taken in 2024, then the first capsule flight in Cargo version could take place in 2028, and the first human spaceflight from Guiana Space Centre could occur by 2030!

9. Conclusion

Such initiative would of course come in addition to the current commitments Europe has made, mainly at international level for exploration. It is obvious that it would require a high political commitment leading to additional funding.

Then, it could be very easy to kill: it is useless, money could be spent in a much more useful way, even in Space, and anyhow we do not have this money…

However, we believe such development would give a very strong sign of “optimism” for the future. It could clarify the question of independence for Europe with a program, for once, not just part of a general vision for which Europe does not have all the keys; it would be a first step towards European autonomous exploration, as a key contribution to cooperative actions with all partners at worldwide level.

It would most probably bear a strong socio-economical interest for French Guiana. We believe it could be felt as a strong, large, innovative, federative program, purely European, not just part of a larger cooperative program.

As mentioned previously, it could be a great motivation for younger generation, excellent for developing STEM at all levels, giving an objective for the next generation of students.

“Dream is alive”: this program could act as the founding vision to permanent presence in LEO, opening the gate to frontier less horizons, open for exploration, in the future.

It appears strategic for Europe to occupy Low Earth Orbits as a major power in the current multipolar world.

Giving the final quotation to astronaut Dr. Claudie Haigneré who kindly advised us during the study: “***you don’t get anywhere with your dreams, unless you start the first step***”