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Human spaceflight: what strategy for Europe?

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HUMAN SPACEFLIGHT: WHAT STRATEGY FOR EUROPE?

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SUMMARY

Since the beginning of the space age, Western Europe has sent over forty astronauts into space, taking advantage of opportunities offered by the Soviets and Americans and participating in the International Space Station. ISS funding, according to current agreements, is due to be modified or even abandoned after 2024. The present Opinion No.10 of the Air and Space Academy (AAE) raises the question of the European strategy to be adopted for the ensuing period.

This Opinion lays out the deep-seated reasons for Europe to continue these flights. It lists the possible missions, which are ultimately few in number, and examines their difficulties and the orders of magnitude of their associated costs. Without knowing what rules will be in place in 2024, we examine three possible ways of achieving these missions: independently, in bilateral or in multilateral cooperation. It is in this context that AAE is appealing to the European Space Agency and national space agencies of Europe to establish a strategy that includes a funding plan for the attention of participating countries, and even European taxpayers in general, as well as providing a medium-term perspective for current and future astronauts.

1. SOME HISTORICAL MILESTONES

It was Serguei Korolev, the father of Sputnik, who launched human spaceflight, after a lifetime spent promoting it. The subsequent exploits of Gagarin and his successors naturally forced the Americans to respond in kind. This was the Cold War: no expense was spared given the political stakes. This first stage began in the sixties, culminating in the famed "race to the Moon" at which the US beat the Soviet Union. The latter never succeeded in developing the required launcher to send up a crew. After Korolev's death in 1966, the main Soviet manufacturers failed to come to an understanding. Naturally the regime long denied its attempts to go to the Moon, and pursued a major human spaceflight programme. This was the era of space stations Saliout 1 to 7, then the Mir station, with a regular turnover of cosmonauts launched by Soyuz.

On the American side, the Apollo lunar programme was discontinued as soon as the race had been won, and the last three launches of Saturn V never took place. There was an attempt at a station with the Skylab programme, based on a converted third stage Saturn launcher, but this was soon brought to an end to make way for the crewed Space Shuttle programme. The Americans then focused their efforts on the Shuttle until the Challenger accident in 1986, which highlighted the great difficulty of the American concept. The idea of cheaper launches and space trips for non-space professionals was abandoned.

The Soviet Union also embarked on the development of a shuttle, called Buran, launched by the powerful Energya launcher. A single unmanned test flight was carried out in 1988 before the programme was abruptly halted. Energya and Buran remained grounded. The Challenger accident had cast doubt on the safety of shuttle flights and provided the opportunity for the older generation of

Soviet engineers to advance the robustness of the "old" Soyuz system. The operating costs of Buran were very high, like those of the American shuttle, and in 1988 the Soviet Union was in no position economically to bear such expense. Nevertheless, after the series of small Saliout stations, it continued its space station programme in the 1986-1996 period, developing and assembling a large modular station called Mir ("peace" in Russian), the modules of which were sent into orbit by the Proton-K launcher. The space station was routinely occupied by three cosmonauts; crews were transported by Soyuz, with refuelling performed by Progress. Even if the modules that had been planned initially could not all be launched for budgetary reasons, the Mir station in its final version weighed over 130 tonnes. Many scientific experiments were carried out there, notably in the field of human physiology, which was essential for long flights. 104 cosmonauts from 20 countries took turns on board Mir during its 15 years of operation.

During this time, no other space nation developed an autonomous project in the field of human spaceflight. There was of course the first Western European[1] to be sent into space: Jean-Loup Chrétien travelled on Soyuz in 1982, then in 1988, visiting first the Salyout 7 and then the Mir station. In all, eight missions aboard Mir were conducted by French astronauts.

ESA's interest in human spaceflight was initially focused on scientific research within the space environment. Commissioned by NASA in the mid-1970s, the agency developed Spacelab, an inhabited space laboratory consisting of a habitable module and/or scientific instrument pallets embedded in the cargo bay of the Space Shuttle. In addition to this European contribution to the Shuttle programme, ESA recruited its first astronauts in 1978, mainly, but not exclusively, for Spacelab flights. The body of ESA astronauts was expanded with new selections in 1992, 1998 (inclusion of European national astronauts) and 2009, and by 2017 comprised 16 members. All these astronauts, in addition to some European national astronauts prior to 1998, were engaged on Space Shuttle or Soyuz space missions, with the Mir and ISS space stations as frequent but not exclusive destinations. Today (2019) and in the near future, all space flights involving ESA astronauts will be headed to the ISS International Space Station. Two ESA astronauts were also engaged on Hubble telescope maintenance missions in 1993 and 1999.

1 The first European was in fact a Czech, Vladimir Remek, who flew on Soyuz 28 in 1978.

With regard to the development of autonomous crewed spacecraft, an important milestone was the decision taken by Europe at the 1987 ministerial meeting in The Hague. It stipulated a three-year study phase to define a spaceplane, Hermes, and an autonomous station, the Man-Tended Free Flyer (MTFF), serviced by Hermes and inhabited only when the Hermes shuttle was present. These were the only attempts at human spaceflight outside the United States and the Soviet Union. It is possible that China was considering moves at the time, but it did not yet have a visible agenda.

In 1989 came the collapse of the Berlin Wall. This event would have a significant impact on space programmes, especially those involving human spaceflight. Americans feared that Russia would sell its space technology (and therefore ballistic expertise) around the world, and specifically to "uncontrollable" states. They therefore constantly endeavoured to control Russian production and to link Russian developments to their own. This was the period of "Joint Ventures" between US and Russian industries: Lockheed and Krunitchev for the Proton launcher; Boeing and Yuzhnoye-Energya for the Zenit launcher. Most importantly, the Americans succeeded in persuading the Russians to abandon the Mir station and to join them as equal partners in the future International Space Station (ISS) they were studying. The Russians agreed, destroying the Mir station in 2001. They and the Americans jointly operate the International Space Station.

On the European side, the opening up of the former Soviet Union caused detractors of European spaceflight to argue that Europe should not act alone with Hermes and the MTFF, but should include Russia. The Americans also wanted the Europeans to join the ISS. They made the same offer to the Japanese and Canadians. The Hermes and MTFF programmes suffered, especially since this was taking place during a period of economic recession. They were eventually stopped at the Grenada conference in late 1992. Two less ambitious programmes were later set up in replacement: an ISS module, Columbus, under German management with a high level of participation from Italy, and the ATV (Automated Transfer Vehicle) cargo vehicle, with France as prime contractor, that was capable of docking automatically to service the station. Japan developed roughly the same elements: a module and a cargo ship. From time to time a European astronaut spends time aboard the ISS under provisions accorded to Europe as a small shareholder (about 8% of the shares of the station).

On this basis, Europe has continued to send astronauts to the ISS. The last selection of astronauts took place in 2009. It included:

- Lucas Parmitano (Italy), for a six-month mission in 2013, then a further mission in 2019 which he captained;
- Alexander Gerst (Germany), for two six-month missions in 2014 and 2018;
- Samantha Cristoforetti (Italy), for a six-month mission in 2014-2015;
- Andreas Mogensen (Denmark), for a ten-day mission in 2015;
- Timothy Peake (United Kingdom), for a six-month mission in 2015-2016;
- Thomas Pesquet (France), the last of this selection to have flown, for a six-month mission in 2016-2017.

In 2003, China sent a man – Yang Liwei – into space for the first time. Since then, five other human spaceflights have taken place. During the most recent Chinese crewed space mission in 2016, with Shenzhou-11, two taikonauts stayed in orbit for the first time: Jing Haipeng and Chen Dong carried out a 30-day mission in the Tiangong-2 space laboratory. The pace of the Chinese inhabited space programme nevertheless remains very measured. There is no longer a race to the Moon!

2. THE PRESENT SITUATION

The International Space Station is in place. Its construction was basically completed by 2009, although additions have been in progress ever since. Since then, it has been permanently occupied by six astronauts: American, Russian, Canadian, Japanese and European. For crew transportation, the station is served only by the Soyuz launcher since the decommissioning of the American Shuttle. This Russian monopoly will come to an end when the Americans have qualified a new means of transport. The Russian Progress regularly supplies food and equipment. The Europeans put an end to their ATV contribution after five very successful missions. The Japanese have launched four HTVs and will continue. The American resupply space-craft Dragon (SpaceX) and Cygnus (Northrop-Grumann) also regularly travel to the ISS with supplies.

NASA has selected two manufacturers – Boeing and SpaceX – for crew rotation at the station. The SpaceX Crew Dragon made its first (crewless) flight in early 2019 and the Boeing CST-100 capsule is scheduled to follow. NASA is funding another capsule, Orion, developed by Lockheed with a participation from Airbus, which will provide, at least for the first two flights, the service module, derived from that of the ATV. But this capsule seems intended for planetary exploration alone, and not for the ISS, reflecting American space policy which aims to distinguish between the “commercial” low orbit and purely governmental space exploration.

With this spirit in mind, NASA was instructed to offer access to the ISS from 2018 to new international partners and expand its commercial uses in order to attract private funding for maintenance of the station. This should enable the US to put an end to direct state support from 2025.

The Russians, much less enthusiastic about this cooperation than at the outset,

are nonetheless complying with it. It is worth bearing in mind that the astronauts are all still being launched to the ISS and that the country no longer has the financial means for independence as in the days of Mir. The Russian space sector is currently undergoing restructuring and budgets are much more tightly controlled than before.

In December 2016, the Europeans decided to continue their participation over the same period. The Japanese and Canadians have taken the same approach.

The ISS will exist until 2024. Over 135 billion dollars (2017 value) have been invested in the station, which is fully operational. Difficult then to discontinue it even if the scientific results obtained in the ISS are much slimmer than expected. Has any review been made of scientific research carried out in the station? Such work does exist, but is little publicised, which presumably means that the results would not elicit much enthusiasm in taxpayers.

As for China, it is pursuing its policy of low orbit stations. After Tiangong 2, which comes to an end in 2019, the Chinese are planning to launch a station with a longer lifetime in orbit, Tiangong 3, around 2022. They are inviting other nations to participate.

Human spaceflight projects going beyond the low orbit are emerging, mainly to the Moon. NASA is due to complete development of the SLS heavy launcher which will make this type of mission possible. The agency plans to install a space station near the Moon known as the Lunar Orbital Platform Gateway. This station aims to be a relay for robotic or crewed missions on the lunar surface and potentially to other bodies – Mars or asteroids. The United States is open to international partnerships, but plainly under US leadership. It is currently unclear as to whether the lunar village idea championed by the European Space Agency will fit into this American project.

China also has ambitions for lunar missions. It has just landed a probe on the dark side of the moon and set a telecommunications relay satellite into orbit around the moon. There is no doubt as to its determination in this area to pursue a robotic and probably an inhabited programme, including a permanent Moon station.

Lessons from the ISS programme

The main legacy of the ISS programme will probably be its success in federating the forces of most advanced nations around a very ambitious international

project. This cooperation, which has lasted for 25 years, has stood up to all the various difficulties, in particular:

- the loss of the Columbia shuttle in 2003, which raised major doubts as to pursuing station assembly operations and finally led to decommissioning of the shuttle, with the result that crews have relied purely on the Russian system Soyuz for over eight years now;
- diplomatic tensions with Russia (Crimea, Donbass);
- changes in governments, majorities and therefore policies in most of the cooperating countries;
- the major financial crisis in 2008 and its aftermath, with budgetary difficulties especially on the Russian side, ...

3. THE FUTURE

Until 2024, and even beyond, the International Space Station will continue to have the monopoly of crewed flights, with the exception of the Chinese programme, which is progressing at its own pace. What strategy for Europe after the ISS? This is the question the present analysis will attempt to answer.

What possible missions for human spaceflight?

First of all, we will draw up a list of all missions that are physically possible for crews, without addressing the needs to be met by these missions. Such an inventory is feasible because the number of possibilities is limited. We can also roughly estimate the costs involved, in order to have access to some orders of magnitude.

Humans might live in a station or stations orbiting the Earth. This is in continuity with the current situation, although several variations are possible depending on the orbital planes selected. Russian-American cooperation forced the choice of a 51° orbital inclination to maximise the load capacity from Baikonur. A different choice of orbit could provide a better basis for leaving the Earth and performing inhabited or automatic missions.

Would there be one or more stations? One station should reasonably suffice, but American-Chinese rivalry can be expected to persist. Russia could (albeit with difficulty) regain its independence, and India might also embark on the adventure. The most likely scenario would seem to be a two-station world, Chinese and American. Other countries – Europe, Canada, Japan or emerging countries – could join these stations. Everything will depend on the geopolitical situation in coming years...

The cost of these stations could be lower than that of the ISS (which cost about 135 billion dollars 2017), depending on their size and crew capacity. Can we imagine building a station ten times cheaper? Maybe not, but a third of the cost would seems more realistic. Let us take as a reference point about **40 billion dollars 2017**.

Humankind could return to the Moon. Technically, this has already been done, albeit taking risks that may no longer seem acceptable today. For example, the return trip was performed on a single engine!

These missions are nonetheless feasible, but with very high costs. We must not forget that rocket propulsion has not experienced a technological leap in terms of the necessary thrust power. A class of launchers such as the American Saturn V or the Soviet N1 would have to be envisaged for this type of mission. Capable of putting a hundred tonnes into low orbit, they weigh about 3,000 tonnes at lift-off. The future NASA launcher, the SLS, will have a slightly lower capability of 70 tonnes to low orbit. The new European launcher Ariane 6 will be capable of setting 20 tonnes into low orbit and 8.5 tonnes into lunar transfer orbit. Will it be necessary to provide in-orbit assembly, which introduces another form of complexity and therefore high costs? The cost of the Apollo programme was 175 billion dollars 2017. The cost of a return to the Moon would probably be equivalent, around **$150 billion (2017).**

A station placed in a near Moon orbit, around the L1 or L2 Lagrange points of the Earth-Moon or circumlunar system, could, as the Americans think, serve as an intermediate station for missions to the Moon or to other bodies of the solar system. It might present more advantages than a lunar station: less energy required for re-supply, no problem of Moon dust... The costs of such a mission though would not be radically different to those of lunar missions.

The last possible mission is a crewed trip to Mars. This is a very ambitious mission whose feasibility has yet to be ascertained. It would certainly require preliminary expeditions to prepare for the landing of humans on Mars, establish telecommunications and navigation means around Mars and also install equipment on and around the planet to prepare for the return trip. There is absolutely no question of sending humans on a one-way trip to Mars. No government (because this type of mission is beyond the reach of private funding) could possibly accept the ethics of such a plan!

A crewed mission to Mars would be very expensive. Rough estimates indicate that the cost of such a mission would be an order of magnitude greater than that of the International Space Station. It can be estimated at over **$1,000 billion**. Which probably explains why, despite much talk, no government has yet dared to officially commit to funding it.

There are no other possible missions. Mercury and Venus are too hot. The big gaseous planets would engulf vehicles and humans. Their satellites are too cold or, like Io, subject to dangerous volcanic activity and intense radiation. As for leaving the Solar System, this is absolutely not feasible with current technologies and barely conceivable in coming decades.

4. THE BENEFIT OF CREWED MISSIONS

Given the costs involved, we have every right to question the relevance of such crewed missions. Are humans indispensable in terms of the intended mission goals? Let us first define these goals more precisely.

Goals can be of a scientific, commercial or cultural nature, or to provide public services.

Are any of the possible missions likely to be **commercial**? It is hard to see how mining activities in the Solar System, with the return of material to Earth, can be profitable. One must bear in mind that a space mission cannot transport heavy weights. The Apollo lunar missions each eventually brought back only three astronauts and their luggage, comprising film reels and moon stones, i.e. a useful return of roughly 300 kg for over three million kilograms on the launch pad (a ratio of one to ten thousand). So those who imagine there could be any commercial application to bringing back material from Mars, asteroids or the Moon, are dreaming. Let us imagine for a moment that we have a way of extracting extremely valuable matter, worth 100 times the price of gold per kilo. If we are capable of bringing back 50 kg per launch, we would make 150 million euros, not even enough to pay for the large launcher used. This is without factoring in the unspecified but undoubtedly very high costs of extraction nor covering operational costs. And yet some people are getting very excited about the prospect of bringing back helium 3 from the Moon. It is true that this helium 3 could be used to produce energy by nuclear fusion. But, aside from the fact that this has never yet been achieved, the density of helium 3 contained in the Lunar regolith is low, of the order of 10^{-8} to 10^{-9}. One would have to extract at least 100 million kilograms of regolith to obtain one kilogram of helium 3! Since it is out of the question to separate the two on Earth, a dedicated factory would have to be built on the

Moon itself. This plant and the associated mine would require a level of investment that is completely unknown. Is it even possible to build them?

It is worth noting that the main commercial space applications – for purposes of telecommunications or observation – use only photon exchanges with zero mass.

Are humans useful for **scientific missions**? The response of the scientists themselves is clearly in the negative. Their reasoning is simple: for the cost of a crewed mission, a great number of robotic missions can be funded. And given the steady progress in robotics, drones and artificial intelligence, it seems highly unlikely they would change their minds.

There is one further aspect that stems from the evolution of mentalities. It is viewed as less and less acceptable to place humans in high-risk situations. When those countries that master space technologies decide to wage war, they seek "zero deaths". Without the spur of political confrontation, as in the Cold War period, there are fewer and fewer reasons to send humans into hostile environments.

Scientists nonetheless concede that if crewed flights are to be performed, they will seek to use those astronauts to best serve their mission goals.

It is also difficult to imagine any **public service missions** supporting the operation of an orbital station, or crewed journeys to the Moon, Mars or asteroids.

5. CULTURAL ROOTS OF CREWED FLIGHTS

This rapid overview demonstrates that the importance of crewed missions cannot be fully grasped without understanding **their eminently symbolic nature and cultural resonance**.

Crewed flights are undeniably extremely popular all over the world. When an astronaut makes a presentation, they are sure to attract a large audience. Their missions are related in all the mainstream press. Television channels clamour for interviews and guest appearances. Public interest in them never wanes. They are admired, perhaps not as heroes, but as the daring representatives of the obscure world of engineers and technicians, ready to carry out missions and demonstrate the high technical prowess of their country. Space missions involving astronauts are a source of inspiration for young people, with a real impact on choices of school and university courses, and a ripple effect benefiting scientific careers in general. There is therefore clear public support for crewed space flights.

The passion inspired is perhaps similar in nature to that prompted by other great adventures: the scaling of the highest peaks, round-the-world yacht races, Arctic and Antarctic crossings ... but stronger, because the scale of the effort requires the participation of an entire nation. It is this symbolic significance which explains why human spaceflight is perceived as a demonstration of power and know-how. And yet such exploits do not actually make countries more powerful (unlike the fact of possessing nuclear weapons, for example): they only demonstrate this power. People from all countries attribute value to this activity – a value that is symbolic and non-commercial but universally acknowledged, thus forming the basis for prestige. It is significant moreover that this demonstration

has, so far, been fundamentally peaceful. It remains to be seen what the cultural or even anthropological foundations of this "value" might be.

According to astronauts Jean-Loup Chrétien and Claude Nicollier among others, human beings are born explorers. The "gene" or, from another point of view, the "need" for exploration has existed since the dawn of time, to support the survival of humans and their offspring. Some even claim that it is in the line of Darwinian evolution: 300 million years ago, animal life emerged from the aquatic environment and spread to the mainland. Soon, it could leave the Earth for other stars ... The head of SpaceX, Elon Musk, considers that our blue planet will soon not suffice for its large population and that other spaces must be conquered rapidly. We cannot however adhere to the idea that this action can take place in the short term (it is fraudulent to suggest that some of humanity could move to other destinations in coming decades) nor even consider this prospect to be desirable, since its inherent logic would have the effect of pushing the ecological safeguard of our planet to the background.

In fact, regardless of the reasons given, this broad interest for sending human beings into space is above all the expression of a certain civilisation. Historically it may have been linked with the ideology of infinite growth, conquest and appropriation, but today it seems to be moving towards an approach advocating greater respect for the "universal" environment, as can be seen in astronauts' commentaries.

In the short and medium term, human spaceflight remains a matter of emotions, and this is not to detract from it. It is the expression of human adventure at its highest level. In his speech for the fortieth anniversary of CNES, the philosopher Michel Serres argued that humans have always endeavoured to increase their knowledge, but that this knowledge included *experience*. This word, he recalled, stems from two prepositions, *ex*, which means departure from our environment and *per*, which describes the passage into a new environment. He added that true experience is felt by the body and not just the mind. Despite our world of communications, virtual reality and artificial intelligence, the public still attaches great importance to the "body" and to bold action. Humans experience the astronaut's adventure by proxy and in communion with them.

Political leaders are aware of all this to a certain degree. Their support for crewed

flight may fluctuate but never fails entirely. As a result, although its fundamental motivations are neither scientific, commercial nor even strictly rational, human flight will continue, despite being more expensive than robotic spaceflight. The two are not comparable, since they belong to fundamentally different registers. However, it is important to emphasise that, once humans are present in space for this type of symbolic mission, they can accomplish many important technological and scientific tasks.

6. POSSIBLE STRATEGIES FOR EUROPEAN CREWED SPACEFLIGHT

Given the above, it is clearly out of the question for Europe, one of the great space powers, to relinquish its policy of sending Europeans into space. In this case there are two possible strategies: the first is to opt for European independence, the second is the path of cooperation.

The choice of independent European crewed flights

In this scenario, Europe would pick up the strategy it had tried to set in place in 1987 at the Hague Ministerial Conference. At the time, a dual concept had been considered: an autonomous means of transport, the Hermes spacecraft, and an independent orbital station, the MTFF (Man-Tended Free Flyer), to be served by Hermes and its crews. Since then, despite the cessation of these two programmes, Europe has increased its technological skills in the areas of re-entry and life in orbit. It has performed successful re-entry demonstrations for the ARD capsule (Ariane Reentry Demonstrator) and the IXV (Intermediate Experimental Vehicle), launched by Vega. Another achievement was the ATV cargo spacecraft launched by Ariane which successfully served the International Space Station five times, performing automatic orbital rendezvous never before achieved by the Americans or the Russians. Finally, the Europeans developed the Columbus pressurised module, connected to the ISS, as well as the Cupola, mounted on Node 3 of the station, from which astronauts have a magnificent view of the Earth. To simplify: the Hermes spacecraft would be replaced by an Orion capsule launched by Ariane 6 and the crewed station would be derived from Columbus and the ATV. Conducting crewed flights in low orbit around the Earth thus no longer constitutes an important technological leap for Europe.

However, it has to be acknowledged that in Europe, the idea of European astronauts does not arouse much enthusiasm. All astronauts might be trained and paid by the European Space Agency, but their appeal is limited to their own country. The French are interested only in French astronauts, Germans in German astronauts, and so on. This once again underlines the symbolic character of these human adventures and their very strong resonance within the national communities. But at a time when Europe is seeking a new lease of life, one might think that a purely European crewed flight programme could provide Europeans with a new dream and Europe with a new impetus. It is easy to imagine the shared enthusiasm generated in Europe by a Kourou launch of a fully European crew to a space station – even a simple one – built by Europe.

In budgetary terms, the costs of these developments are not necessarily much higher than the contributions required for necessarily more ambitious co-operation programmes. If the chosen programme is of moderate ambition as mentioned above, the costs can be contained in well-defined envelopes. This is not so simple in more complex co-operative programmes in which minority partners are not always free to opt out.

The choice between a strategy of independence and a cooperation policy is eminently political. Before deciding, it is therefore important to examine the course of cooperation as well.

What alliance policy should be set up?

Europe could advocate that crewed spaceflight is a matter for all of humankind and that future programmes should therefore be placed in an international context including all space nations that wish to be involved. Efforts on the part of the International Space Exploration Coordination Group (ISECG) to harmonise the situation are timely, but should be more ambitious. In plain language, China and India should be welcomed within the current consortium for the International Space Station. This future human spaceflight programme could become an exemplary venture for the world as a whole, demonstrating that nations are capable of cooperating to build large-scale projects together. There is no doubt that such cooperation would be a factor of dialogue and peace in our competitive world and could help avert the growing danger of isolationist tendencies.

This cooperation could take the form of an ad hoc international governmental agreement between all concerned nations. The signatory nations of Europe would delegate authority to the European

Space Agency to execute this agreement. ESA would thus set the overall goal of this vast cooperation and the main elements to be developed in order to achieve it. Partners would contribute in kind. The agreement should be flexible enough for partners to choose the main elements to which they wish to contribute, either alone or as a team, within subgroups of their choice. Any development commitment would clearly have to extend to maintenance throughout operational life. All infrastructures built under this agreement would have to be usable by all partners according to mutually agreed rules.

The agreement would also stipulate the rules of governance for each programme, including the designation and constitution of a system architect responsible for defining and qualifying the entire project as well as managing the interfaces between the main elements. This architect would ensure compliance with operational safety and crew protection regulations that are so vital to crewed spaceflight programmes. Project leaders developing the main elements would, on the other hand, be left very free in terms of their designs, technological choices and component supplies. Each major element would of course have to meet overarching requirements, as in any large-scale programme. Rules for managing changes that impact the system as a whole would also need to be established, ensuring the clear distribution of financial impact.

In this respect, the rich cooperative experience of European nations can be put to good use to procure an agreement that is not unnecessarily procedural and/or complex. It is vital to restrict rules to what is strictly necessary in order to achieve as streamlined a management system as possible.

Despite the desire on the part of Europe to obtain a partnership agreement with as many space nations as possible, certain nations may refuse to participate. In this case, Europe must maintain its independence in its choice of cooperative actions. It must be free to choose the joint programmes it intends to conduct, whether with China, the United States, Russia or India, if the latter develops a programme of crewed spaceflights. Under no condition should it agree to exclusivity clauses.

Bilateral agreements to be studied for crewed spaceflight

If Europe wishes to go further than autonomous low-orbit flights, as described above, it must look into bilateral cooperation actions that would enable it to

undertake more ambitious missions, such as participating in a new Moon landing, whilst ensuring a more decisive role for Europeans in the conduct of the programme. Given this last point, neither China nor the United States would seem to be potential partners since they will always want to assert their leadership role in any cooperation. There remains India and Russia.

India has some lunar ambitions but its budgets in this area remain very limited, well under the amounts needed for crewed flights.

An equal cooperation with Russia remains to be analysed. The historical reminder at the beginning of this opinion shows that France and the USSR, and subsequently Europe and Russia, have cooperated in the field of crewed flights with the launch of many astronauts. The Russian Space Agency Roskosmos and the Academy of Sciences recently presented a lunar programme. The political powers would seem in favour of such an action which would boost national pride, as space conquest in Russia has always done. But no funding has been earmarked for this programme; instead a search for cooperation is being advocated because the financial means no longer exist to act alone. Indeed, this is the crucial point. For the past few years, the Russian space sector has entered survival mode. It is existing solely on past achievements and no longer innovating. Russian stakeholders attest to this and deplore the situation. Cooperation with Russia could only be achieved if the Russian state was strongly committed to finding the means for the planned lunar programme.

Of course, some doubt is permitted as to the enthusiasm on the part of Europeans to cooperate with Russia at present, but this search for cooperation could be one way of renewing dialogue with the country. It is worth pointing out that space cooperation has always been conducted in the past despite significant political differences.

What are the goals for an international crewed spaceflight programme?

It is difficult to unilaterally define the goals of a future programme. However, among the possible missions mentioned above, the right compromise must be found between the expenses incurred and the attractiveness of the mission in the eyes of the general public, since they are the main reason for it being accomplished. Without attempting a precise definition, any mission should be ambitious enough to offer a real challenge that is both inno-

vative (after several decades of operation of the ISS) and eminently realistic. Its feasibility should be established without too much difficulty: it is important to bear in mind that the challenge is as much one of global cooperation as of technical success.

What contributions should Europe aim for?

It is difficult to be precise in this area too, since the system to be developed has not been defined. But we can draw up a list of programmes in which Europe has undeniably demonstrated its mastery.

Since the Spacelab programme, and then the Columbus and Cupola modules attached to the International Space Station, Europe has demonstrated its know-how in the development of pressurised modules and life support devices. The ATV refuelling module established mastery of automatic docking, paving the way for assembly in orbit, which will doubtless be required for future major missions. Europe's participation in the Orion crewed capsule, for which it produced the service module, itself derived from the ATV experience, can find applications in terms of the service module(s) that will undoubtedly be a feature of the future international programme. It is worth noting too that Europe is perhaps the only player to have sent a probe around the Moon using electric propulsion alone for the transfer from Earth orbit.

These are some elements then in which Europe could play an effective part. The selection criterion could provide that one or more elements should showcase European action in this venture. A feeling of pride must emerge in Europe through the development and operation of the programme. We must make sure that Europeans are aware of their positive role in the concert of nations, a role that could not be carried out by any single European nation in isolation. This must be a key political goal of European crewed spaceflights.

7. SETTING UP A ROADMAP

The International Space Station will definitely operate until 2024 and perhaps beyond if maintenance costs do not become prohibitive. However, details of the key crewed spaceflight programme(s) that will ensue are beginning to emerge. We have shown that decisions are of a political as well as a technical nature, and are liable to swing between these two levels. It will therefore take time to decide which cooperative framework Europe wishes to commit to, or whether it will act autonomously. It is at the highest level of European governments that such decisions must be taken and we know that in Europe the decision-making process can be long. Time will also be needed thereafter to establish credible funding schemes and timetables, especially since some of the options in these programmes may be carried out in a new international context.

The Air and Space Academy is launching this reflection, but it is up to the European and national space agencies to look deeper into the various possibilities: autonomous programme, bilateral cooperation or multinational cooperation. Each of these avenues deserves to be explored, analysed and compared. In this sense, AAE recommends setting up a roadmap immediately to precisely define European strategy for crewed spaceflights for the coming decade.