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From Apollo to Amazon – Ground Control Changing

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Abstract

The recent announcement of Amazon Web Services Ground Station, a novel service from the enterprise that aims at easy and cost-effective data download from Earth orbiting satellites into its global cloud computing infrastructure by a fully managed network of ground antennas located around the world, has raised major attention in the space community. However, it only marks the latest, logical move of the still emerging NewSpace industrial branch, which, after capturing the space and transfer segments of astronautics, has shown increasing interest in entering the ground segment. Where established mission operation centers tend to be mired down in layers of licensing, regulatory processes, standardization and mission-by-mission operations, new players equipped with self-defined and flexible degrees of freedom could become real game changers. This especially holds true, if paired with strong motivation and supported by gigantic financial backing.

In our paper we focus on ground control, investigating the evolution of spaceflight from the Apollo era to cloud based computing. We find that technological leadership is seemingly not the main element driving disruptive changes in this area. Instead, a solid business model outside the box of classic astronautics and a strong focus on the users of space-borne products might be the key to success. We show the pros and cons of such an approach, also displaying possibilities for classic mission operations and ground control style. On this backdrop, we suggest a change of paradigm towards the de-centralized control of spacecraft to keep abreast of the societal digital transition.

Keywords: Mission Operations, NewSpace, Cloud Computing, Ground Control, Control Center, User Orientation

Nomenclature

Cloudification – The process of migrating applications and services from local infrastructure to a web-based distributed resource. These web-based resources require an Internet connection and often offer on-demand services. Typical example would be a web shop with simple access/user control. Provided locally, such functionality is cumbersome, while the same thing provided in a cloud is out-of-the-box.

Acronyms/Abbreviations

Amazon Web Services (AWS),
Asymmetric Digital Subscriber Line (ADSL),
Columbus Control Center (Col-CC),
European Cooperation for Space Standardization (ECSS),
German Space Operations Center (GSOC),
Ground Station (G/S),
Information Technology (IT),
Interface Control Document (ICD),
Integrated Services Digital Network (ISDN),
International Space Station (ISS),
Internet Protocol (IP),
Launch and Early Orbit Phase (LEOP),
Mission Control Center (MCC),
Personal Computer (PC),
Radio Frequency (RF),
Software Defined Network (SDN),
Space Link Extension (SLE),
Ultra-High Definition (UHD)
Very / Ultra High Frequency (VHF/UHF),
Very High Speed Digital Subscriber Line (VDSL),
Virtual Private Network (VPN)

1. Introduction

Since the turn of the millennium space flight has undergone major modifications. While in its initial stages it has been exclusively cherished by only a few governmental bodies, today the whole industrial branch profits from a contrasting pair of streams of development: both governments as well as commercial endeavors often lead by private enthusiasts put heroic efforts in the exploration of space as the final frontier of humankind. Where governments, under pressure to justify public expenditures, are moving towards large overhead expenses in highly regulated research and development programs, private investors are at liberty to spend surpluses at their own discretion. We believe NASA's NewSpace Industries Workshop held in Washington D.C. in February 1998 a cornerstone of this transition [1]. Well over 20 years later, it seems that a great portion of what was designed back then to facilitate the goal of space development comes true.

Consider for example the realization of orbital public space travel [2], the emergence of reusable launch vehicles [3] or the planned conversion of the International Space Station (ISS) into a commercial space business park infrastructure [4]. Eventually, an ever growing plethora of privately funded, profit motivated space ventures has come up all over the globe [5]. In light of this, it is hardly surprising, that one of the world's largest companies by revenue, Amazon.com, becomes involved in the field likewise.

Whereas the term "NewSpace" is widely tied to the transfer and space segments at present, Amazon.com brings the ground segment into the focus of its latest space project, Amazon Web Services Ground Station (AWS G/S) [6]. Complementing access to their cloud services by a network of radio-frequency (RF) antennas, AWS enters the Earth observation and services market to diversify its portfolio. Incidentally, the company shakes the whole space sector to the very foundations, as it promises access to its fully managed global network of ground stations to become a lot easier and much more cost-effective than the current systems. Considering this a serious claim, here we analyze the impact of this *cloudification* of the ground segment in more depth. Regarding traditional mission control centers, we focus on ground operations and control systems.

The subsequent text is organized as follows: in section 2 we describe the (technical) evolution of a typical ground segment from the Apollo era to the present, before we critically review the cloud-based approach in section 3. Section 4 describes the results of our survey and section 5 concludes the text at hand.

2. Evolution of the Ground Segment

In 1961 the USA decided to go to the Moon within a decade, practically starting from nothing. Back then it could have been described as extremely ambitious, or to quote the US president John Kennedy "hard". Today we would realistically call it "impossible".

At that time the biggest problem was the "how". All other obstacles like funding, rules, laws were comparatively small. Today things have changed, we usually have answers to all the "how" questions. On the other hand, the financial, political and social aspects bring almost any project to tremendous effort, causing financial explosion and extreme delays. For this reason, many projects remain only on paper, in fear of this suffering.

Getting back to the Apollo program – as we know, they made it. They learned a lot of new things, gained experience and it was, just simply, a success. Even the motivation was rather driven by the "Space Race" between USA and Soviet Union and to show who had the overhand, the results were mostly scientific and technological in nature and literally the whole world does still benefit from that [7, 8].

The Apollo missions are of course mainly known for the Moon landing(s), but even so fantastic, this was only a tip of an iceberg – thousands of people have been working hard in research, development, construction, and last but not least at Ground Control.

The mission operations for such a challenging endeavor are neither self-explanatory nor simple. The sending of humans into space – compared to the first rocketry experiments and satellites – imposed completely new requirements to many aspects of the operational environment.

The Ground Control at that time formed into what we know, more or less, until today. The entire system was developed around the Mission Control Center (MCC), the heart of ground facilities. The MCC was directly connected to the antenna sites, allowing communication with astronauts and monitoring of spacecraft parameters. The flight dynamics was located just next to it. Everything was supported by rudimentary, at least from today's point of view, computing equipment. There were only a few mainframe machines performing important calculations and a handful of display systems.

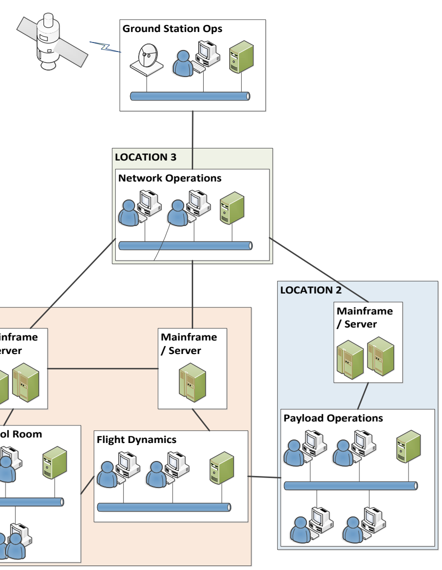

Fig. 1. Typical schema of MCC design in early stages

Fig. 1 schematically shows the ground segment as described. The design provides the MCC as a central part surrounded by network operations, ground stations and payload operations. The MCC itself contains primarily computing facilities, control room(s) and flight dynamics. Network and payload operations may also be co-located with MCC; often the payload operations, in particular, was placed closer to the actual scientists processing the data.

An important aspect of any space mission is reliability. The systems were expensive and sophisticated at the time, but far from being highly reliable. Spare parts and redundancy were very important, although not easy to implement. Thus, the design and logistics of backup and redundancy became an integral part of space operations. The project manager had to take care of various scenarios in the event of a device failure, secure sufficient replacement components and system backup, but not put the project budget in deficit.

2.1 Ground operations at GSOC 1969

More or less at the same time as the Apollo mission culminated, the German space program - in cooperation with NASA - began to grow. First the Ground Station in Weilheim was initiated, and barely a year later had the construction of GSOC begun.

The GSOC building was set up around the control room (see Fig. 2) respectively the complete infrastructure had been organized to support the satellite operations in that room. The “so called” support rooms, computational facility (see Fig 3), which more or less corresponds to today’s server rooms, as well as normal offices were located in the immediate vicinity of the control room itself. It has to be said that a small team made things a bit easier, as this allowed placing things very close to each other, thus saving space and cabling.

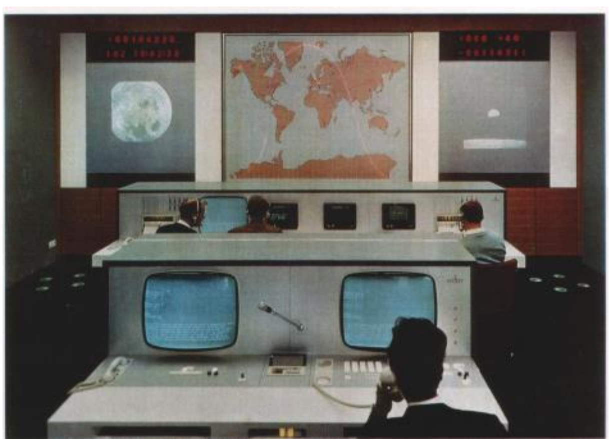

Fig 2. GSOC control room for AZUR satellite, 1969

The specialization of the staff was not as advanced as it is today, and most team members had a broad knowledge of the overall system, from the communication link to the processing units and the control room itself, just to mention the hardware. The complexity of the system was limited at that time, so such a generalization was relatively easy. This also had an impact on the operational aspects, making it easier to replace or support team members in critical situations or absences.

Fig. 3. Computation facility at GSOC for AZUR satellite, 1969

Most of the processing units in the computer system were specially prepared for use in the space operations center. This is not surprising, since at that time there was hardly any selection of ready-made universal systems. Only a few manufacturers of computer equipment were present, but each installation was followed by debugging and adaptation to the customer's needs - here the MCC.

2.2 GSOC 1991

Throughout the years until the late 1980s and early 1990s, many gradual changes took place in the ground control systems. Computers became more powerful and cheaper, following the development of spacecraft and more complex mission profiles. This was the intensive period of geostationary telecommunications and broadcasting satellites, which required more and more systems.

Also operationally things changed, the teams became bigger, more specialized. Computers and networks began to become important not only for purely operational reasons such as telemetry processing or orbital dynamics calculation, but also for recording, reporting and ultimately for all office-related work. This led to more infrastructure requirements that suddenly differed significantly from what was required for purely operational reasons.

Perhaps one of the most important things that happened in the early 1990s was the Internet. Evolutionary for almost three decades, things had just grown larger, more powerful, faster and more complex, but had somehow retained their basic structure. Then, in less than a decade, Internet and mobile communications changes, accompanied by social transition, changed the world. It should be noted that Amazon and Google were born in the late 1990s, well over 50 years after space exploration and its accompanying ground systems were originally developed.

The control room at GSOC had partly changed since 1969 (see Fig. 4). There were more displays, most of them showing colors, keyboards and buttons were more universal and covered less space than before. The team was bigger, and the room itself had grown.

Fig. 4. GSOC control room for ROSAT satellite, 1990

In addition to the backend server systems, which provide the main computing power for operational use, personal computers (PCs) were installed directly in the control room or in the offices around them, providing the staff with office-related processing facilities.

Fig. 5 shows a schematic representation of the overall system. Note that not much has changed since the late 1960s. Every single component of the system was replaced several times by better, faster and more reliable versions, but the entire system design remained unchanged.

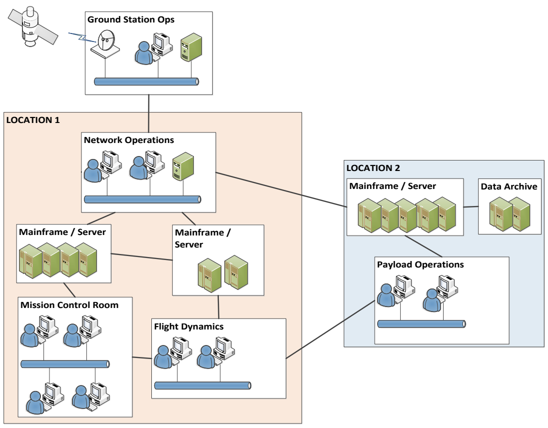

Fig. 5. Schematic representation of ground control system in 1990'es

Malicious gossip said that the message behind all this was the following: if you wanted to fly a satellite, you had to hire a lot of specialists, build a facility, fill it up to the roof with computers and spend a lot of time and money on all that. Maybe it was exaggerated, but not really far from reality.

2.3 GSOC today and Col-CC

The Columbus Control Center (Col-CC) for the European Columbus module on the International Space Station [9, 10] was an important engine for renovation and modernization in the late 1990s. Long-term continuous operation led to the development of new systems, a fiber optic network infrastructure, and the implementation of a storage area network for a long-term data archive. The high availability requirements for manned space missions led not only to the development of highly redundant systems and infrastructures, but also to the creation of a backup control center environment. A new, separate building hosts a cloned computer, voice and video infrastructure as well as backup control rooms. The continuous operations lead to a further cloning of the systems to operations, simulations and test instances.

Operations support processes were more and more digitalized using web-based tools instead of paper. This accelerates work and even simplifies things. Of course, such tools require an effort on the IT side of the business - additional servers, software and personnel to maintain it. Interestingly, in some cases the paper version is retained as a backup solution. This shows that we don't really trust this digitized world or maybe we are just realistic. After all, whether online or offline, in digital form or on paper, the actual processes remain the same.

The ground segment of the satellite missions was also combined into a certain form, which can be seen very clearly as in the DLR TerraSAR-X mission [13]. Operation centers (mission operation, payload and instrument) take advantage of their own specialization and the dedicated infrastructure available.

Currently the teams are much smaller than before - at least for operations. On the other hand, staffing levels for back-office tasks (such as quality assurance, documentation and security) have increased. IT-relevant jobs have also become extremely complex and specialized.

Modern network and computer technologies enable several new approaches that allow simplified, but not small, cabling and complex logical structures at the same time. In this way, multiple projects can run in parallel on the same infrastructure without interfering with each other. This makes investments more effective and projects more cost-effective. Nevertheless, the complexity shifted from physical (cables, PCs, etc...) to software, which has to manage all project-related components. And so there is still a lot of effort with backup, redundancy and obsolescence. The accounting aspects are also becoming more and more complicated. Where it used to be easy in an organization to buy another server or router and transfer it to the cost of the specific project, it is now almost impossible to account for a particular network segment or virtual machine and its use by a project. A company's accounting department cannot handle virtual machines so easily because they do not have serial numbers and are not inventoried as such. On the other hand, they cannot be treated as software. Companies have learned to accomplish all this with some more or less dirty workarounds; yet it gets worse with each iteration of the technology.

The server facilities themselves meet the highest requirements in terms of redundancy, cabling concepts and cooling (Fig. 6). The use of modern firewalls, routers and smart switches enables the formation of complex project-related logical structures that effectively comprise what is known as a Software Defined Network (SDN). This allows contradictory concepts such as Open Access and high security to be combined - previously only possible through strict physical separation.

Fig. 6. GSOC server room, as of today

Furthermore, virtualization and, as a next step, container technology offers a multitude of advantages for administrators and projects. Cloning and setting up new systems has never been easier. At the same time, users can decide to deploy their required software or systems faster and be ready for re-testing in the shortest possible time in the event of a failure of some components. One of the biggest advantages of virtualization is also the decoupling of virtual systems from hardware, which enables hardware maintenance to be conducted in a way that is almost completely transparent to virtual system users.

Virtualization [11, 12] was used by GSOC as leverage to provide what we call virtual control rooms. As shown in Figure 7, the control rooms seem to be very similar to what they were before, except for obvious things like flat screens. However, this similarity is not complete. All terminals are currently identical, not only in this room, but in all GSOC facilities. They are now only used to connect remote desktops to current display systems on virtualized machines. This means that the user can log into his project machines from any individual operating position in the entire control center. This increases flexibility for the user and, above all, efficiency when using control rooms. In this way, we have avoided setting up new control rooms for new projects and can provide LEOP with almost overlapping services.

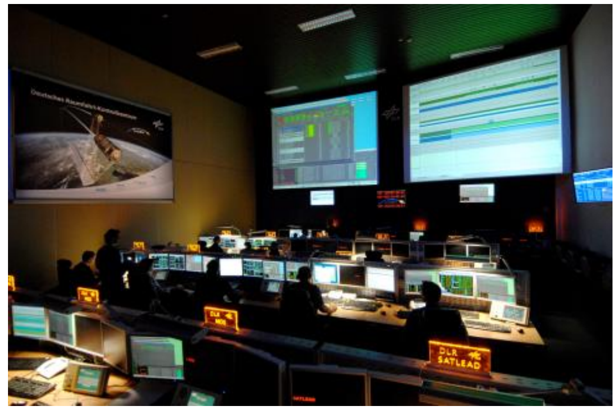

Fig. 7. GSOC control room for TerraSAR-X and TanDEM-X satellites, 2010

We can take a look at Fig. 8, which shows today's setup at a very high level. It looks as if some weights have been shifted, with less operational staff and more computing facilities. At some point, however, the entire setup looks very similar to the one we presented earlier and which we have known for many decades. We argue that this corresponds to the typical evolutionary development. And it can go on.

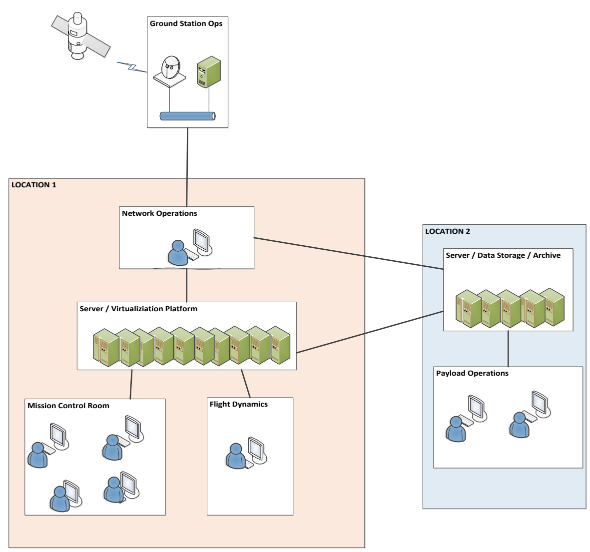

Fig. 8. Today's typical setup of ground control for space operations.

2.3 NewSpace experience in classical setup

NewSpace questions the traditional approach in terms of time management and information availability. The development of a NewSpace satellite mission is much faster and tends to be more difficult to structure. In DLR's own CubeL project [14], a scientific experiment satellite is operated with a laser communication payload. Since the satellite bus is a small 3U Cubesat, the traditional massive ECSS project management approach is not suitable. Since Cubesats usually only have VHF/UHF antenna systems on board, familiarization with VHF/UHF technology is the key to a successful mission. The manufacturer offered a complete UHF ground station with the satellite bus. During the implementation of the ground station we encountered some unexpected obstacles and had to work closely with the manufacturer to meet these challenges. We experienced that on the one hand the effort for the preparation for the mission could be reduced, on the other hand obstacles could not be avoided completely due to the unknown area. In the end, the effort for a successful mission could be the same when new, unknown problems arise.

Another example is the Flying Laptop, a satellite built and operated by the University of Stuttgart [15]. The space probe itself is almost a typical small satellite class. The only difference is that it runs on many components that are not necessarily space-proven or certified, but similar to what we know today from laptops (hence the project name). This was one of the main ideas to prove that the satellite, built with relatively cheap components, can be operated successfully and can also perform some additional experiments. Since the satellite was built by the university team, the budget was very limited. Also for launch and operation, the university team only had to deal with a few aspects that were not necessarily clear. DLR provided support in these areas and supported LEOP with its know-how and the DLR ground stations, in addition to the university's own antenna on the roof.

There were few new or good things to learn for the university, but such a mission appeared to be a challenge for DLR. Since there was hardly any financial support, we had to reduce most of the typical things we do for LEOPs. We didn't care much about project risk matrix or configuration control items and focused exclusively on hard core things - the absolute minimum to get things going. The only official project document that was created and exchanged was the Interface Control Document (ICD), in which we kept the setup and configuration of our interface between the university and GSOC. The communication link was set up as a VPN over the Internet. To avoid further developments, the Space Link Protocol (SLE) was used. This required an additional deployment on the campus, but worked well in the end and the cost was limited to a few hours of work and a desktop PC.

The mission is a success and the support from GSOC - even if it is extremely low-key - we feel as very rewarding. It showed the flexibility of the teams and at the same time broadened our horizons with another experience. You can launch and operate spacecraft (even relatively large ones) with limited resources.

3. Review of cloud-based approach

Let’s look at the core issue of this text, starting with some advantages and disadvantages of the cloud-based approach to ground control. The AWS ground station created the link between the ground station as a service and cloud computing services. This combination allows customers to easily build the ground station infrastructure with minimal hardware investment. The concept of the AWS ground station is to place the antennas in close proximity to existing AWS data centers. The customer books the time on an antenna and plans a contact with the customer's satellite. The downloaded data is immediately inserted into the customer's cloud environment for further processing. This reduces the infrastructure required to operate a satellite contact to a workstation with Internet access to access the AWS console. In terms of cost, AWS does not distinguish between uplinks and downlinks. The cost of this service is $3-22 per minute, depending on the service level.

Fig. 9 shows a schematic representation of the ground infrastructure for cloud-based operation. There is a significant difference; users are no longer tied to a specific location and services are provided from the cloud. Users can select the services as required and, for example, apply the "pay-per-use" principle. Ideally, for such a scenario, the entire ground segment mutates into a black box for the user with all its advantages and disadvantages.

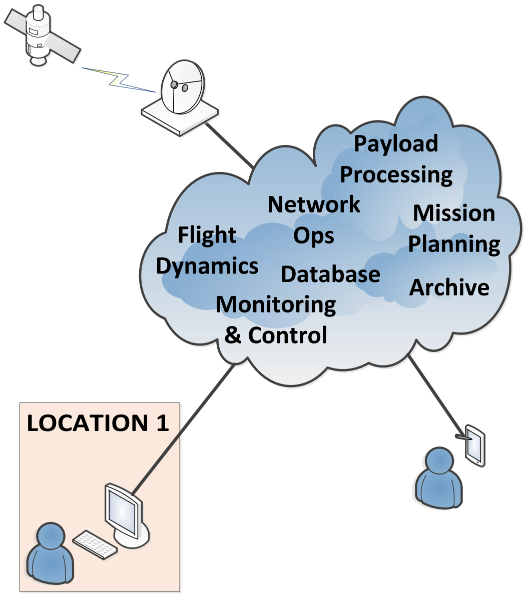

Fig. 9. Cloud based mission operations.

3.1 Pros and Cons of Cloudification

From a technical point of view, the low demands placed on customers for the first steps in "doing things" are all in one hand. No complex network or security access considerations are necessary, even monitoring and control systems for the spacecraft may be set up in such a way that they are suitable for generally technically qualified personnel. This can actually increase interest in space applications and should definitely serve as an opportunity. On the other hand, we shall not forget that the ease of use (Internet, mobile phones) does not really mean that everyone uses them only for productivity and good things. Wide reach also means a wide range of applications and (mis)uses. Are cloud providers willing to discontinue support for a malicious mission at the request of law enforcement? Who decides when the mission is good, useful or not? Current discussions with the social media world and the question to what extent users need to be monitored and when providers need to intervene are the best examples.

In most cases, the cloud-based solution is pre-baked, so the time from the first contract signing to the first operational test is very short. Due to the characteristics of products, many cloud-based solutions will be easy to learn and use. This can even lead to voice assistants-like operations ("Alexa, tell me where my spaceship is and give me the main household parameters").

The cloud services are based on a real service level agreement. This means that there is no micromanagement from the customer, which gives the provider freedom and frees the customer from cumbersome tasks. Similar to any telecommunications provider, Internet and telephone services are available at home, where you don't care if it's ISDN, Voice over IP, ADSL or VDSL. Even the information about the actual bandwidth is not really important as long as streaming your favorite series in UHD works. The same goes for your spacecraft, as long as you know in time how your spacecraft is doing and can react quickly to problems (which can also be monitored by a service!), you don't care how it happens. Moreover, by service thinking, you and your mission feel relieved of various responsibilities. This gives people time for focusing on the actual merit of the mission.

The cloud systems are designed to be available anywhere and at any time. This has a huge impact on your operations concept. With the availability of your computer or processing resources as a service, you can have virtually unlimited resources and scale to meet your needs. Operators could work from home, sub-system engineers would not have to be physically present during on-call shifts and the mission management would have 24/7 access to all relevant information. Facilities were more or less obsolete. In essence, spacecraft operations would take place in a completely virtual environment very much like in a multi-player online game.

For some cases it also simplifies cost forecasting (there are only a limited number of price tags and you know them in advance), but predicting services actually used later can be difficult due to the frequently used "Pay as you go" policy. This is a situation of planning shopping with cash (you have limited amount in your portfolio, so you plan and do not spend more than this) or with credit card (you have some limit on a card, but usually higher than you normal purchase value, so you tend to spend more). Now the cost estimate no longer ends with the purchase or setup of the service itself, but also the use of the service generates costs - and there may be more than one actual user of the service, both working independently. By analogy, we would say a shop with the credit card and at the same time his partner with another credit card, which in the end is connected to the same bank account.

For providers of cloud services, a small, in this scope, advantage has to be considered. If they have new customer groups in their portfolio such as ground station services, they optimize the further use of their infrastructure -with many customers having complementary needs. Here, the mass effect enables a rapid increase in efficiency and offers customers a better and more cost-effective service.

The ability to capture data can be a big advantage for the provider, depending on his actual goals and the type of business case he is serving. Today, especially for companies like Google or Amazon, it has become clear that data collection and mining can offer significant potential, and for these companies it can bring them to the most valuable businesses in the world. One could imagine different service levels where customers choose their privacy depending on the price at which they are willing to pay. And as life shows, the majority of customers will choose the cheapest - and offer the cloud provider almost everything on a silver plate. This can even go to the extreme.

It is also worth mentioning the image of the supplier, which can show its versatility and participation in various market segments, in this case the space market. Whether this is also beneficial for users or customers remains a question, but the small sticker or logo in the mission's control room with the words "Cloud Services provided by..." is definitely worth considering.

The data collection mentioned above can be a serious issue for customers. Especially with commercial providers there is no guarantee for a real transparency about what really happens with the data stored or processed in the cloud. With today's setup, for example, most of the sensitive missions (military, security) can decide not to use cloud services. Even for many universities or smaller companies, the risk of losing their intellectual property to third parties (possibly even unnoticed for a long time!) is too high and can lead to a decision against the use of such cloud services. It can be said at this point that at least in the case of AWS, the operator is making some efforts to overcome such problems [16, 17] and even support the requirements of military missions [18]. However, this is still limited to the specific case of the US DoD and may not be consistent for other countries.

Another point worth mentioning is the low level of cost transparency. This is not always a disadvantage, especially if missions are only "one-time" or short-term and the use of a certain computer infrastructure can therefore be regarded as a "black box". However, as soon as missions try to plan long-term or repeat a flight, the question of cost drivers and the reasons for them can be interesting. And in general, even with the service level based cloud services, it will still occupy a considerable position in the total mission costs. Most of today's service providers are not really interested in providing details about their service (e.g. power consumption costs, personnel or travel costs). This varies from provider to provider, but is in principle an integral part of the service delivery.

The user has no direct control over the entire system. This can mean that in critical situations you are completely dependent on the cloud provider's ability to bypass the problem. It doesn't necessarily have to be a disadvantage, as the respective service levels can guarantee very high availability and reliability, but this still requires a rethink.

Due to the bankruptcy or other significant business problems of the company offering cloud services, the provision of these services can be abruptly stopped. In this case, the space customer may be legally entitled to a cash refund or other compensation, but in the case of the spacecraft, this may mean an imminent loss of the mission. Do customers have to take care of the backup solution? Is it at all plausible to have two parallel cloud providers? These are questions that need to be answered in the long term.

3.2 Pros and Cons of the Classic

Current - let's call them “classic” - cloud providers are usually out of business. That doesn't mean they work wrong, but there's still only a small portion of ground control systems that take advantage of cloud systems. The space business has so far been too small to be a serious business case for cloud providers (especially the smaller local ones). The requirements, on the other hand, are partly specific, so that the use of cloud systems out-of-the-box is not possible either (e.g. connection to a ground station and provision of tracking data).

Looking at a specific space mission control environment as the classical approach, we find several negative aspects associated with it.

If you need to rebuild a ground control from scratch, you need to invest in infrastructure and construction work, i.e. buildings, water and power supply, communication lines, storage, etc., but also in the actual space communication hardware such as computers / colocation centers, control room equipment, etc. You also need to identify one or more suitable ground stations to which your radio signals can be sent.

A further disadvantage is time: the commissioning of the entire necessary infrastructure usually takes a few years.

Last but not least, you need to identify, hire and pay well-trained personnel. As already mentioned, employees are usually highly specialized and are therefore highly courted. Attracting qualified employees to naturally remote locations (good antenna sites are usually not located in cosmopolitan areas) can be a big challenge.

If you are in the fortunate position of already being equipped with an operational ground control center, you still have to take over the corresponding operating costs and keep your staff busy and productive. If you are a user of such a system, you will be billed according to the requirements of your mission, which may be more expensive than the cloud-based approach due to a lack of extensive standardization.

The space missions to be supported, however, benefit from a high degree of transparency and direct interaction with the operators as well as from high flexibility and reliability, since everything can be tailored to the mission requirements.

Over time, staff will not only specialize in space or specific subsystems, but will also acquire expertise specifically related to the particularities of a single spacecraft or mission, especially at the end of a spacecraft's life where contingencies are more common. In addition, the appropriate working environment facilitates the acquisition of idealists who are consciously willing to contribute to human space research.

Designed as isolated solutions, data centers are highly secure in the classical approach and the respective room segment is difficult to attack from outside the control center.

Finally, the visibility and collaborative networking at the international level - at least for the time being - is a unique selling point of classical control centers, from which many space endeavors have benefited.

4. Opportunities for Ground Control Cloudification

In our opinion, the AWS approach is a step into the right direction, at least with respect to the optimization of efforts.

The biggest problem with cloud-based solutions, in our understanding, is a lack of transparency and a latent suspicion that all activities of the commercial provider are aimed at maximizing profit. This prerogative is (or at least, will not be) the desired one for national space agencies, educational institutions, or whatever we call it, is not necessary from a social point of view. Nevertheless, all this taking into account the fact that someone might come to the conclusion to install his control center in the AWS cloud. Someone will do that sooner or later, no doubt about it. However, we are not convinced that this is the right way for institutional operators and agencies. Rather, we propose to set up a kind of "agency cloud" that meets all the requirements. There is already the so-called academic network, which offers backbone services to all universities or agencies, a good example of a service that spans almost all countries and at the same time serves special purposes for all participants and gives them freedom from the commercial world.

One could imagine every agency setting up their current computing systems in such a way that cloud services are possible for other agencies or universities. One could envisage such a cloud of clouds that would be seamless for each individual project, enabling better use of resources while providing the project with almost infinite resources at a moderate cost.

The most important technologies (virtualization, containers, etc...) are already known and in use, but scalability can be a problem for government agencies. Large companies such as Google or Amazon have a lot of experience in this area, and the agencies would have to make considerable efforts to achieve the possibilities of a seamless expansion of computing capacity with simultaneous transparency of the changes for the users.

Interestingly, the cloud provider can host customer systems and missions while running its own missions. As another example from the Amazon world shows, for the first time it seems contradictory that this can work well for everyone. The Amazon marketplace makes it possible to sell similar or even the same products as Amazon itself, but at different prices or slightly different conditions. At the end customer of end products decide, and even if this may not be positive for both with every single decision, the common platform gets more attention in the end, which statistically also means a better turnover for all.

Now, if you transfer this to the ground control cloud systems, you could imagine an agency that offers cloud services and at the same time flies its own mission (with the same infrastructure, by the way). Suppose the mission delivers optical images in a special wavelength of agricultural areas. Now another mission provider can get a cloud space from our agency that is flying a similar mission, but with a different resolution or repeatability, for example. Classically one could see it as competition, but in this case, since both missions use the same infrastructure and possibly share the same systems, software and interfaces, it seems more than plausible that both missions can be put together as a kind of meta-supplier of images, which again delivers a broad, perhaps even cheaper product spectrum to the end customers, makes them happier and brings them back again in the future.

Thus the coexistence of several missions in a cloud - from large and complicated missions to different types of constellations and individual CubeSats - can be feasible and even desirable, especially from the point of view of the national authorities. And so the agencies, which suffer from financing problems and compete with commercial providers, can regain their important role. But this time they are not doing "space things", they are providing a platform to do "space things". Nationally or institutionally in general, cloud providers would be transparent, without pressure on commercial profit, i.e. open to many sensitive (military, national security) or only deficit projects (university, open source or basic research).

6. Conclusions

With this work, we have questioned both the way we have been operating spacecraft for more than 50 years, and the supposed promise of salvation of some new actors like Amazon.com. Established ground control concepts have much in common with the historic Apollo program and therefore tend to be age-related. Novel developments use the main advantages of cloud-based infrastructure sharing and a high service orientation.

When it comes to high demands on flexibility, transparency, mission security and security, space missions are well advised to rely on Apollo-like ground control systems. However, where timeliness and low budgets are the main drivers, cloud-based ground segment solutions could perform very well and have a number of pleasant side effects.

On the flip side of *cloudification*, mission owners lose direct access to the infrastructure and have no influence on its design. In addition, they must adapt the space segment in such a way that it is adapted to the respective cloud system in a standardized structure characteristic.

To get the best out of both worlds, traditional ground control centers could join forces. Establishing a cross-agency cloud for spacecraft operations as a counterpoint to the spin-in ventures that are emerging not only has the potential to reduce overall mission costs while maintaining quality, but also opens up the prospect of profiting from the advantages of a distributed system. It could take ground control to the next level and eventually churn out a fortune.

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