Cloud an Innovative platform for cost effective mission operations?

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The volume and processing needs of spacecraft data is growing exponentially due to technological advances. This data needs to be processed, stored, and queried. It is often made available to communities that will add further value through additional processing for their communities to create benefit for European citizens and industry. Operators need to achieve this yet must continuously strive to improve efficiency and lower operational costs. Can the cloud provide solutions that address these objectivities?

Cloud-based computing promises significant advantages to the space industry including improved expenditure control, reduced operational complexity, improved time to market, the encouragement of innovation by scientists and the ability to deliver new solutions that were not previously feasible. Control of expenditure is achieved by reducing capital spending, providing predictable costs matched to actual research activity, eliminating technical refreshes and delivering high utilisation. Operational complexity is decreased through simplified pricing models and SLA agreements across participating organisations. The reduced need for capital investment means that investment decisions are far easier to justify, and that initiatives can succeed (or fail) quickly and cheaply – with no long term financial commitment for the program; further, cloud computing allows the rapid scaling out of resources to respond to un-anticipated demands. A cloud infrastructure provides rapid access to computing services and leading-edge architectures in which scientists can innovate freely. Finally, cloud computing encourages cross-organisational collaboration and provides an environment where divisible calculation-intensive problems can be run in a fraction of the time that a traditional data centre would take.

Today's economic climate is adding further pressure to mission management to reduce costs yet maintain quality, security, system trust and efficiency. Logica with experience from a number of space cloud initiatives will in this paper cut through the hype of cloud and provide clarity to operations and development teams on what, how and where cloud can be considered. The paper will examine some use cases of potential usage in operations processing, data archiving and operations consolidation.

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I. Introduction

Cloud computing started in the late 1990s as Internet organisations (such as Yahoo, ebay, Google and Amazon) experienced explosive demand from individual users and had to evolve their data centres, networks, services and operational processes to respond to this demand while keeping costs and the quality of their service under control. Later, after they had mastered many of these challenges by developing highly streamlined data centres providing highly standardised commodity services, they realised that other organisations could benefit from something similar and so started to offer commercial cloud services. While this was very successful and worked well for "utility" services (such as providing virtual machines, storage, e-mail and collaboration capabilities) clients have more sophisticated needs and today there is a tension between delivering these standardised services on a large scale and providing something better adapted to specific needs particularly when Service Level Agreements (SLAs) and regulatory compliance are a significant consideration.

Essentially cloud is about the provisioning of computing resources such as hardware, storage, processing and software as a utility. In the same way that your organization uses electricity, water, gas on demand when you need it, today's cloud infrastructure is providing computing resources on demand. Today we are undergoing a shift from the prior client/server technologies of yesterday to cloud computing of tomorrow, although clearly cloud will not fit every scenario.

From a survey we conducted within the public sector, we found that almost a quarter of clients put 'cutting business costs' as their top role for the cloud, as did the majority of clients from the local government, public safety and justice, and space and defence subsectors. In addition space and defence clients put 'lets us focus resources on more important projects' as their major business reason. The top 5 reasons for cloud by our public sector clients are illustrated below.

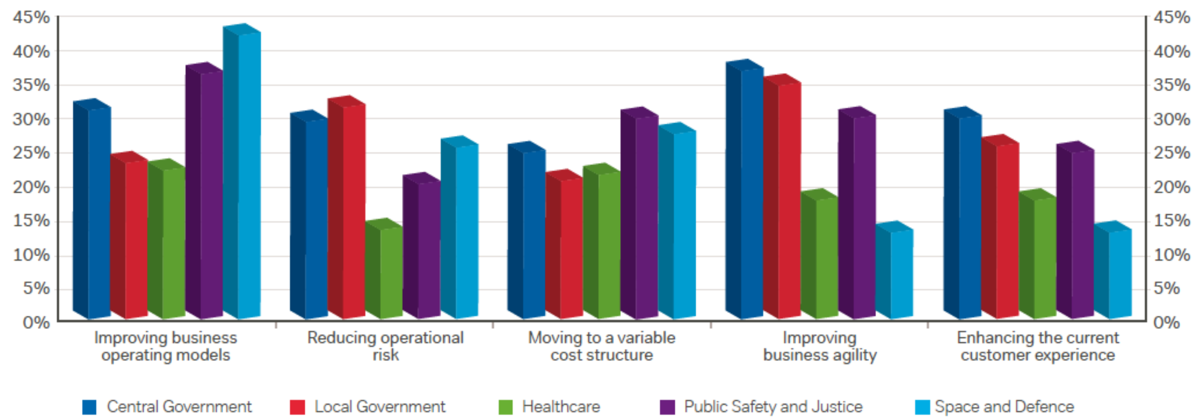

Figure 1. Logica Public sector survey top 5 reasons for cloud adoption

The space industry has already readily adopted the cloud in certain fields and continues to explore and identify beneficial areas for the adoption of cloud within the industry. NASA's Mars rovers Spirit and Opportunity become the first NASA space mission to use cloud and in 2010 NASA began work on developing its own cloud computing initiative, Nebula. Nebula set a vision to provide a cutting-edge, dynamically scalable computing platform capable of meeting the agencies standards. ESA has additionally over the last few years been using cloud for a couple of years successfully particularly in the scientific and earth observation arenas. Just like in the early 20th century when people were highly skeptical about the car and its take up, yet it transformed almost every facet of our lives. Much like railways which made it possible for the farmers to sell their goods at further distances, when it becomes easier to do something with someone else than by yourself, people trade, and you get growth. Cloud is a paradigm we are still learning and shaping but it offers serious potential to reconsider how we conduct spacecraft operations to improve efficiency, increase collaboration, reduce risk and extract value. While cloud computing may sound like hyperbole, it is not a just another paradigm shift, it's the largest shift in the history of IT to date.

Chris Kemp ex NASA CTO said, "Cloud is the area that has really gained traction at the agency. Using the cloud in this way has also helped NASA with efficiency. Kemp said typical utilization of infrastructure is 20 percent but Nebula allows NASA to run at 80-90 percent efficiency."

II. The cloud model

Cloud computing is a model for procuring readily available on-demand computing resources that can be easily provisioned and released, and can be accessed typically over a network or the internet. It encompasses three fundamental service models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a Service (SaaS) see Fig. 2.

Infrastructure as a Service (IaaS) is concerned with the provision of infrastructure resources such as physical or virtual computers, raw storage, firewalls, load balancers and networks from a cloud provider typically via a self-service web-based portal. Within this model, the consumer is responsible for the management of the underlying infrastructure such as the operating system and any relevant upgrades and patches. Additionally, they are also responsible for advanced features such as managing and configuring load balancing. There are a number of different deployment models for Infrastructure as a Service:

- Public: Resources are provisioned within multi-tenant publically accessible infrastructures and are charged via a pay-per-use model. Within this model, it is considered that the cost benefits of Cloud Computing are the highest. However, large organisations may be reluctant to operate within public clouds due to concerns about running jobs involving sensitive data in multi-tenancy environments.

- Community: Common infrastructure shared between organisations that have similar security, compliance and jurisdiction concerns e.g. governmental or military organizations, industry eco systems.

- Private: A shared infrastructure for use by a single organisation that alleviates some of the fears of running jobs involving sensitive data in a cloud environment. However, this model is often criticised for reducing the cost benefits that can be realised through using a public cloud, although larger organization that can pool resources with correct payloads could benefit. Private clouds can also be hosted by third parties, in this model IT capabilities are provided by service providers, similar to traditional hosting or outsourcing models but with far more flexibility regarding consumption-based pricing, standardization, and usage flexibility. Providers of hosted clouds offer some of their services portfolio using a dynamic delivery and elastic pricing model (i.e. rent rather than buy). It usually offers higher levels of security and privacy than public cloud; integrates better with existing on-premises IT; provides service levels tailored for the client's specific needs, and allows control of the data centre or country location.

- Hybrid: The composition of multiple cloud deployment models acting as a single entity whilst combining the benefits of the encompassing models e.g. an organisation could operate a job within a hybrid cloud combining a public and private. Normally the job would run on the private infrastructure. However, should a job experience a sudden burst in required resources than the maximum currently available within the private infrastructure, the additional work can be pushed out on the public infrastructure.

Platform as a Service (PaaS), the next level of abstraction from infrastructure, is more about the provisioning via a self-service portal of key services that are exploitable by an application, such as message queues, application servers and databases and offer on-demand scalability. The services are typically made available via APIs. Some PaaS services may provide a development environment in which to orchestrate these services. Within this model, the consumer has no responsibility for underlying infrastructure such as the operating system, network and servers. Essentially, PaaS is about simplifying the complexities of deploying and operating large scale applications.

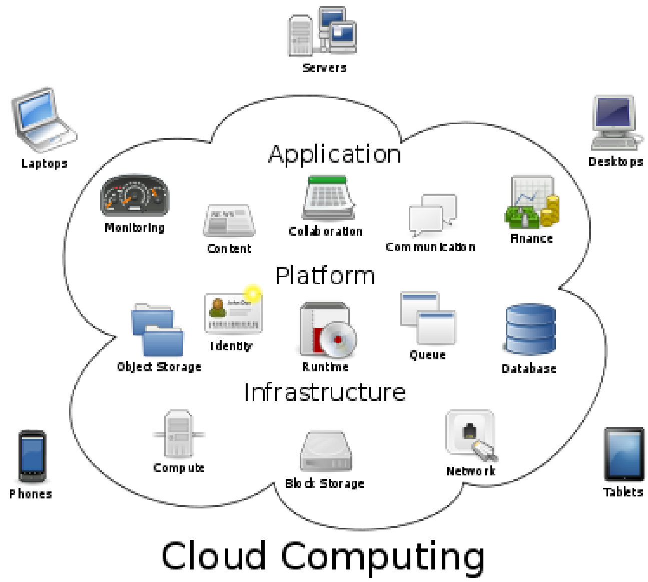

Figure 2. Cloud computing model (src http://en.wikipedia.org/wiki/File:Cloud_computing.svg)

Software as a Service (SaaS), sometimes referred to as 'on-demand software' or application on demand, is a software delivery model in which software runs within the infrastructure of the provider and is accessible by the consumer via a thin-client such as a web-browser. Typical software products offered under the SaaS umbrella include email, word processing tools, project management software and Customer Relationship Manager (CRM) products, although that is by no means exhaustive. Indeed the number of SaaS services is continuously increasing. As with PaaS, the consumer is not responsible for management of the underlying infrastructure and additionally within this model, the consumer need not concern themselves with the installation of patches or upgrades to the software as this is all managed and controlled by the vendor. Other potential benefits are that the initial investment in the software for the consumer is lower as they do not need to cover setup and hardware costs themselves. It is expected that the software should be self-scaling and payment models typically differ from traditional software models in that they are more focused on pay-per-use or pay-per-user models.

III. Cloud benefits

If a mission manager is able to map at least one requirement against the categories provided here that its highly likely cloud will provide some benefits if not then cloud is probably not a good option:

Potential Cost Savings

- Avoiding capital spending: allowing an initiative ability to succeed (or fail…) quickly and cheaply, and requiring a lower level of executive approval (however, the costs of internal project initiation, architecture and design, business consultancy, etc. will still require up-front investment)
- Predictable costs match business activity: you only pay for what you are using (but the TCO is likely to be higher if the system is used heavily for significant periods of time)
- No technical Refresh: budgets do not have to be found for mid-life upgrades as the price is included in the OPEX payment (however, you will have to move to newer releases quickly, with the potential additional retesting and compliance costs)
- High utilisation: less underutilised hardware (particularly useful for solutions with significant failover and redundancy requirements).

Reduce Operational Complexity

- Simplified pricing & SLA model: the pricing and service levels are streamlined and easy to understand (though limited in their scope)
- Offload nonessential processes: IaaS processes may include storage services, development and testing environments, backup, failover, B2B communications, etc.

Agility – Reduce Time to Market

- Rapid business innovation: bring new services on-stream without many of the significant overheads introduced by internal IT (however, a number these internal IT processes are important for SLA or compliance reasons, and will not be avoided – despite the necessary delays they will introduce)
- Handle un-anticipated demand: examples include transport web servers during bad weather; ticketing solutions for popular events; etc.

Leverage provider & user innovation

- Provide rapid access to new capabilities
- Offer leading-edge architectures
- Providing enterprise "app stores" in specialised cloud eco-systems

New Business Solutions

- Those that were not previously feasible (for example massively parallel analytics; social enterprise solutions; the provision of highly elastic processing capacity; etc.)
- Superior reliability, scalability & security

IV. Data protection and security

Data security, data sovereignty and data privacy are areas that have to be addressed early when evaluating any cloud solution: if these aren't satisfied then there is no cloud opportunity to follow. Specifically, there are three key issues that have to be answered:

- What threats does your cloud solution present to your existing systems, applications and data?
- What are the best security approaches to balance your requirements against risk in both a public and private cloud deployments?
- What new security technologies & models are available to address your cloud security requirements?

When it comes to risk and compliance, there are four areas to consider; these are the same as in a traditional data centre. There are the legislative aspects such as those around data protection, freedom of information, the regulation of investigatory powers, and computer misuse. Secondly, there are the Regulatory aspects including ISO 27000x security as starting point. There will be a security policy framework, including risk management and accreditation[4]. Thirdly there are auditing considerations, coming from both the EU and from national auditors and commissioners.

Many public cloud providers – such as Amazon and Microsoft – come under US law and are affected by the PATRIOT Act (Uniting (and) Strengthening America (by) Providing Appropriate Tools Required (to) Intercept (and) Obstruct Terrorism Act of 2001). The Act gives US law enforcement authorities the right to access personal data held in the cloud by these companies, regardless of where in the world the data is stored. The Act also gives US law enforcers the right to prevent the cloud suppliers from informing their customers that they have had to hand over personal data, even though this conflicts with EU data protection laws.

You should be aware of the Safe Harbor framework agreement between the EU and the USA. The European Commission's Directive on Data Protection went into effect in October of 1998, and prohibits the transfer of personal data to non-European Union countries that do not meet the European Union (EU) "adequacy" standard for privacy protection. The U.S. Department of Commerce in consultation with the European Commission developed a

[4] This is likely to include Governance, Risk Management and Compliance; Protective Marking and Asset Control; Personnel Security; Information Security and Assurance; Physical Security; Counter-Terrorism; Business Continuity

"Safe Harbor" framework to provide the information an organization needs to evaluate, meet the requirements of – and then join – the U.S.-EU Safe Harbor program. (http://export.gov/safeharbor/).

Most public organisations have a significant perimeter-based security infrastructure for protecting their systems from external threats. This “inside out” approach presents a problem for public cloud solutions, because you often want an external service (admittedly initiated by a company employee) to be able to interoperate with internal company systems – which is an “outside in” model. This is much less of an issue when all systems are outsourced in the same data centre, in a virtual private cloud. This is a significant problem to address as it requires significantly modified security architecture and new operational processes to be defined, approved and implemented. It is probable that more flexible network firewall devices will also be required, and there is also a trend away from perimeter-based security to stateful inspection firewalls which require context-based access control.

Your need to have a clear understanding of the scope of the cloud providers’ outsourced functions, such as monitoring security infrastructure components; firewalls, intrusion detection sensors and antivirus systems; being able to analyse the data they generate for indications of security problems; remote configuration of the security infrastructure components; prevention and remediation of security vulnerabilities and recovery from incidents. You also need to understand whether your security group can give up control to the extent necessary to outsource security monitoring and management; it may be that you enter into an arrangement that includes co-monitoring or co-management.

The security offerings available from cloud providers do vary, and need to be considered carefully. Things are evolving quickly: you can assume that today any service provider will offer denial of service protection, e-mail security, vulnerability scanning and a web security gateway. For Big Data scenarios you also need solid firewalls and intrusion prevention systems (IPS), and key management and encryption is also important.

To safely manage these issues work out the risks for each cloud project, taking into account applicable regulations, data sensitivity and business requirements. Decide on the deployment model (private, public or hybrid) and the service model (infrastructure as a service, platform as a service, or software as a service) depending on the risks. Make sure you integrate security with the existing technical, organizational and procedural set-ups. Evaluate the need to add security services like digital signatures, time-stamping, secure archiving and logs. If a third party delivers the service, make sure you understand exactly what security is in place. Set up and monitor performance indicators for security so you can make sure it keeps doing the job over time.

With cloud if you cannot meet the constraints of the law, satisfy the client’s specific security needs, or meet statutory regulatory requirements then there is no cloud opportunity to evaluate**.**

V. The Space Industry adoption to date

Cloud usage and adoption by the space industry has been increasingly on the rise for the last few years and given the potential of cloud computing this is highly likely to continue particularly as both NASA and ESA are developing large scale IaaS infrastructures the core building blocks that underpin PaaS and SaaS models. This section is not an exhaustive list of the current developments but demonstrates the scale of activities currently in progress.

In America, NASA JPL has moved forward with adoption of cloud quickly with one of the first heavy usages being for the rover’s spirit and opportunity. For the rovers JPL has adopted usage of the Amazon cloud for scientific data processing and to conduct mission planning activities. Images taken from the rovers are stored directly in a public cloud. This operations concept has allowed the NASA team to continuously grow its storage and processing resources using an on demand model. This on demand model of operations where they can elastically control the size of resources available to the planning team has provided the ability to resolve plans in tens of milliseconds, this figure includes all network latency. In addition, to the performance benefits realized by the mission the operational costs had also been reduced from $40K to $13K a noticeable reduction. Furthermore access to the planning databases is easily available to other interested parties within that mission community easily. This particular use case highlights cloud usage at the heart of mission operations.

Additional NASA missions including Mars Exploration Rover (MER) and Carbon in the Arctic Reservoir Vulnerability Experiment (CARVE), have adopted cloud to process large volumes of science data. The use of Amazons Simple Workflow Service (SWF) a framework used to develop resilient, automated and scalable applications provided the means to coordinate all processing activities (Fig. 3). This is a service used by Architects to design an overall workflow both with local infrastructure and cloud. These missions continuously generate large volumes of data which needs to be processed, subsequently stored and then analysed cost effectively and within the performance constraints of the missions. Essentially, the infrastructure is dynamically provisioned to process the data and disseminate it to users within minutes. The added advantage of using a community cloud approach where users and data cohabit clearly opens many additional value chains.

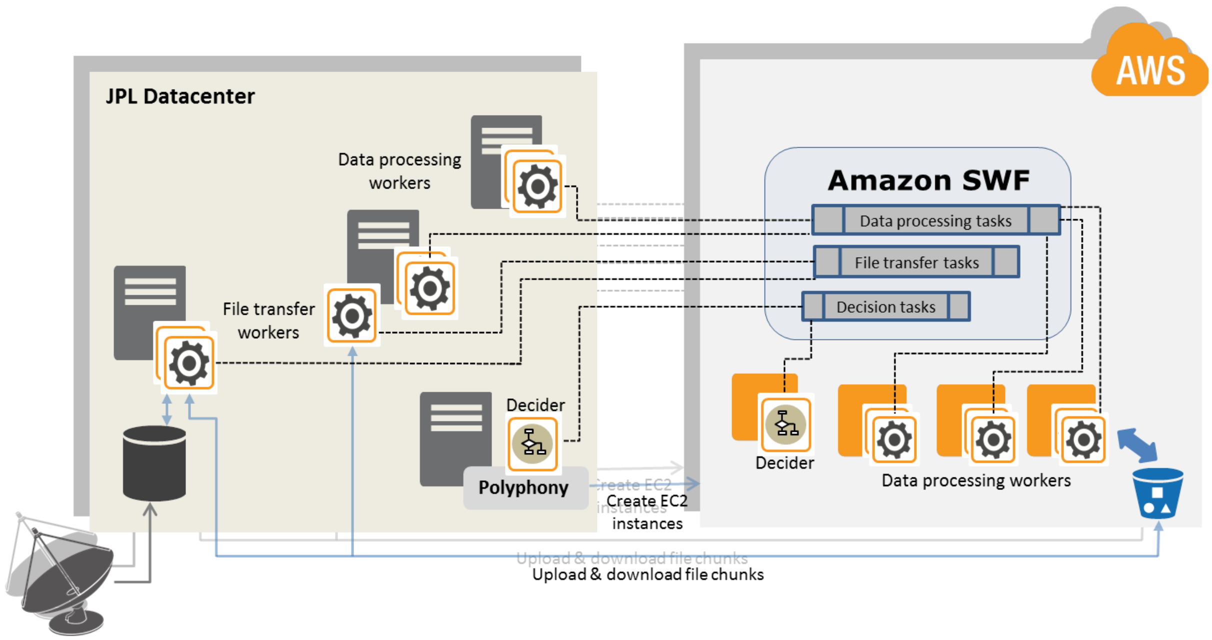

Figure 3: NASA Simple Cloud Workflow Process

NASA has clearly recognizsed the potential of cloud computing to improve its operations efficiency both in terms of cost and overall performance which has been very much influenced by the federal government's strategy on open government. In 2010 NASA launched Nebula, its cloud-based infrastructure-as-a-service environment. The idea was to provide a means of providing large scale compute capacity without the costly construction of additional data centers. Currently there are two Nebula environments, which have been built into freight containers (Fig. 4).

This open source Infrastructure-as-a-Service (IaaS) cloud environment provides scalable compute and storage for science data and Web-based applications. It provides a way for users to automatically provision, manage, and decommission computing capabilities on an on-demand model driven via web or API.

Nebula is an open-source hybrid cloud computing platform that was developed to provide an easily quantifiable and improved alternative to building additional expensive data centers and to provide an easier way for NASA scientists and researchers to share large, complex data sets with external partners and the public. In addition Nebula will offer PaaS and SaaS capabilities to provide improvements in productivity and collaboration. Through these higher level services benefits in terms of rapid development of secure policy-compliant applications, greater reuse of services can be realized.

Nebula makes it far easier, faster, and more cost effective to deliver data driven applications that encourage public participation and user expert collaboration. In this regard, Nebula provides NASA with a cloud community approach improving collaboration with external researchers through shared data and services via high-speed data connections. In addition to the Nebula hybrid cloud American scientists have a further public cloud capability made available to them from the open cloud consortium. This not for profit organisation operates a publically available IaaS computing infrastructure to environmental, medical and health care research fields.

One notable application is the NASA Matsu project which aims to provide a collaborative environment which contains EO satellite imagery data from both the Advanced Lander Imager (ALI) and the Hyperion instruments. The environment makes this data available to all interested parties. In addition to the data services that provide capability to government and other agencies image processing services in times of disaster.

Figure 4: NASA Nebula freight container cloud data center

In Europe, ESA and the science communities have also been experimenting, conducting exploration of applicability of Cloud Computing services to its needs. Among all the different service models of Cloud Computing Services, it turns out that Infrastructure as a Service (IaaS) from public providers over the Internet has been so far the primary solution of choice in ESA. ESA has been making use of public IaaS providers although it recognizes the limitations preventing its applicability to a wider spectrum of users within the agency. To date ESA has been developing for scientists a Cloud based application development environment to implement and test their EO applications through provision of a EO Sandbox. This Sandbox provides a community approach to development prior to deployment. This PaaS like environment provides data discovery and access tools, project management tools such as ticketing, versioning document management and wiki support. The project is focused to exploit the cloud computing models for non-critical systems in the EO space.

In the Science arena the Gaia mission ESA quickly understood the potential benefits of a cloud based approach for its Astrometric Global Iterative Solution (AGIS) which processes all the observations produced by the satellite. The non continuous nature of the data processing needs of GAIA were extremely conductive to a dynamic on demand cloud based approach as processing power was efficiently adopted.

After initial internal testing and modeling it quickly moved forward with a feasibility study based on use of Amazon IaaS and PaaS solutions. Amazon was selected at the time due to the Oracle PaaS provision. The financial benefits were motivating, using Amazon for its processing capabilities would save 400K Euro, not including human effort, bandwidth, electricity or storage.

A consortium of leading European IT providers and three of Europe's biggest research centers CERN, EMBL and ESA have announced a partnership to launch a European cloud computing platform, "Helix Nebula - the Science Cloud". This public on demand IaaS infrastructure will support the massive IT requirements of European scientists and become available to governmental organisations and industry after an initial pilot phase. While similar in concept to the not for profit open cloud consortium, the approach taken is very different. The American strategy is essential to purchase the necessary hardware while in Europe the idea is to federate existing cloud suppliers thereby accessing a large volume of resources. In addition the no single vendor approach provides long term assurances. This partnership is working to establish a sustainable European cloud computing infrastructure, supported by industrial partners, which will provide stable computing capacities and services that elastically meet demand. This pan-European partnership across academia and industry is in line with the Digital Agenda of the European Commission and will foster innovation for science and create new commercial markets.

Volker Liebig, ESA Director for Earth observation programmes, said, "Helix Nebula- the Science Cloud is a partnership with the potential to support an utmost exploitation of ESA satellite data, as well as to bring other communities on board to better understand the geophysical phenomena of our planet."

VI. Potential usage in operations

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On review of the adoptions to date there has been relatively little uptake of cloud within spacecraft flight operations to date. Clearly, there a number of risks and operational issues that needs to be very carefully considered and addressed, but benefits are most certainly there. The mission operations concept will heavily influence the potential of cloud, but there are areas and stepping stones that managers of future and existing missions could analyze in terms of their requirements and strategic objectives.

Many agencies manage data archives for housekeeping and engineering data. Often these archives are silos maintained by each mission. Adoption of cloud computing could open up the potential to pool these archives to open up not only greater efficiencies in terms of resources but additionally to provide greater capabilities to extract their value. In modern IT Hardware development, manufactures can trace back defective equipment right back to initial hardware testing via their IT systems, how many agencies have similar capability? Having a low cost ability to extract value from this data may have great benefit to a large community of users, both within and outside of the organisation.

The NASA rover mission planning system, as highlighted earlier in this paper, uses a cloud based approach, and had a number of tangible benefits. There is no major reason why satellite and science payload planning systems could not adopt a similar position should that be beneficial. An on demand always up to date planning system could be offered as service, with mission managers simply monitoring the effectiveness via SLA.

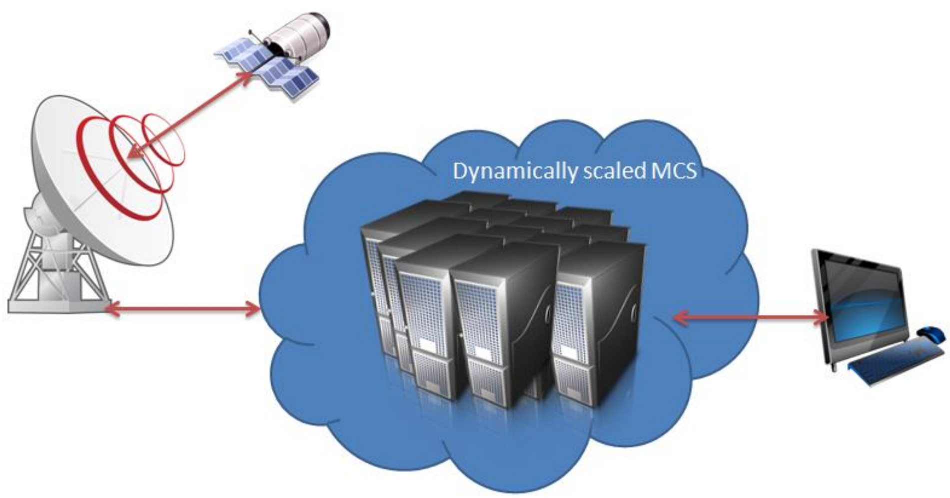

Figure 5: Dynamically provisioned MCS in the cloud concept

Mission Control Systems given the speed of evolution of cloud applications a cloud based MCS is potentially not that far away particularly within agencies looking at private or virtually private cloud environments or indeed those with hybrid models. While certain mission types would not necessarily benefit from this model such as geostationary, or indeed any mission that has permanent coverage. On the other hand, missions with a fixed number of contacts could benefit from higher levels of availability and redundancy. The control system and ancillary systems would be automatically provisioned on demand prior to contact (Fig. 5); in addition multiple redundant systems could be made available with equal ease. For early adopters, as they build trust with such approaches, perhaps only the redundant back systems would be provisioned with the current fixed IT assets for primary systems remaining.

Most agencies and operators disseminate data or products to user communities such as primes, partner organizations, principal investigators, end users and other interested parties. Given that this service is not an always on capability, potential cost efficiencies can be made through adoption of an on-demand cloud based processing and delivery service, which could be provisioned to the scale needed to process and disseminate the data. Users would additionally benefit from a higher performance service and greater levels of redundancy. In this respect, service quality has been increased but at a lower cost.

A cloud solution related to FD operations can be beneficial in different areas: storing, processing and sharing telemetry data, extracting physical parameters, interfacing between various ground stations, FD engineers, mission planners, satellite operators, scientists and end-users, would benefit from a cloud community approach, as all parties would share a dynamic on-demand virtual space. Satellites, in particular Earth orbiting ones, are becoming more autonomous, e.g. on-board attitude and orbit determination using GNSS, so that the operator's role during routine operations is reduced to monitoring the data's health and corrections planned by the system. A SaaS system could cut operation costs if development and maintenance costs can be spread over a multitude of missions. This is in particular the case for orbit determination activities, where the number of acquisition methods vary less between missions. Because non-routine operations require FD operators to perform various calibrations, diagnoses and plan ad hoc actions, ground segments will always include an engineering toolkit. The vision is that engineers prototype and create engineering data derived from telemetry and ground tracking, plan manoeuvres and share data with other interested parties. A PaaS solution can potentially support this vision, whereby FD operators can collaborate in real time both on their tools and their data products.

Clearly, other services such as collaboration tools, testing sandbox PaaS, and development PaaS environments do offer lots benefits in terms of human efficiency improvements (which is a major cost driver) along with increased agility. These areas may prove to be excellent and stepping stone opportunities to explore cloud benefits in a safer environment yet one which can potentially return real benefit.

VII. Conclusion

Dynamic on demand cloud computing paradigm offers great potential for agencies, operators and missions to reduce direct and indirect costs and improve efficiencies between community stakeholders by bringing all parties together in a single shared space consuming resources only when needed. Furthermore, cloud computing provides a means to evolve systems more towards a service based approach which offers the potential to help control and mange costs over a longer period, this is particularly beneficial to the space industry as program lengths have a tendency to be long.

Like any technology cloud is not a magical solution to be applied to every situation, in addition given the security and data protection issues a, robust cloud governance framework is needed, but many agencies are already defining those models. If industry managers are to leverage the benefits then early discussion with suppliers is a must to ensure that their navigation to effective usage of cloud is achievable, and will return the needed benefits.

Appendix A
Acronym List

API	Application Programming Interface
CEP	Complex event processing
CERN	Center for Nuclear Research
EMBL	European Micro Biology Lab
EO	Earth observation
ESA	European Space Agency
ESOC	European Space Operations Centre
IaaS	Infrastructure as a service
IT	Information Technology
JPL	Jet propulsion lab
MCS	Mission Control System
MCS	Mission Control System
NASA	National Aeronautics and Space Administration
OCC	Open Cloud Consortium
OPEX	Operational Expenditure
PaaS	Platform as a Service
SaaS	Software as a service
SLA	Service Level Agreements
TCO	Total cost of ownership

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