Computational Cloud Services and Workflows for Agile Engineering

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Abstract. CloudFlow - Computational Cloud Services and Workflows for Agile Engineering - is a European Integrating Project under the framework of Factories of the Future that aims at making Cloud infrastructures a practical solution for manufacturing industries, especially SMEs. The objective of CloudFlow is to ease the access to computationally demanding virtual product development and simulation tools, such as CAD, CAM, CAE, and make their use more affordable by providing them as engineering Cloud services. It is experiment-driven to ensure that the infrastructure developed matches the actual needs of European industry. The CloudFlow Platform is built in a modular way. It consists of 5 main layers (user, middleware, service, cloud, hardware). The Workflow Manager plays the central role of a broker to hide the complexity of executed chains of services and applications. It allows to invoke and to monitor the execution of services and applications, automating complex workflows with many services.

1 Introduction

CloudFlow - Computational Cloud Services and Workflows for Agile Engineering - is a European Integrating Project (IP) under the framework of Factories of the Future (FoF) that aims at making Cloud infrastructures a practical solution for manufacturing industries, especially small and medium-sized enterprises (SMEs). The objective of CloudFlow is to ease the access to computationally demanding virtual product development and simulation tools, such as CAD, CAM, CAE, and make their use more affordable by providing them as engineering Cloud services.

1.1 Experiments

The project is experiment-driven to ensure that the infrastructure developed matches the actual needs of European industry. Three waves of experiments have been de-

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signed, see Fig. 1. The first wave of experiments is addressing the challenges of end-user partner Stellba for the repair, maintenance and manufacture of water turbines.

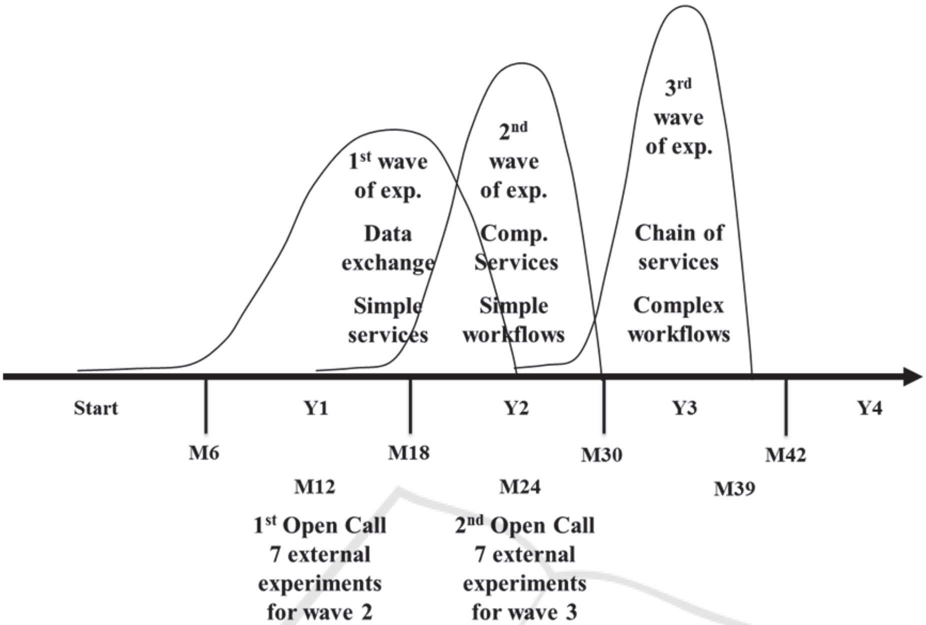


Fig. 1. The three waves of experiments in CloudFlow.

The following experiments are part of the first wave:

- Computer Aided Design (CAD) in the Cloud
- Computer Aided Manufacturing (CAM) in the Cloud
- Computational Fluid Dynamics (CFD) in the Cloud
- Product Lifecycles Management (PLM) in the Cloud
- Systems Simulation in the Cloud
- Point clouds vs CAD in the Cloud

2 CloudFlow: System Architecture Overview

The CloudFlow Platform is built in a modular way. It consists of 5 main layers, which may contain one or more system components. From the end user perspective all the layers are seen as a whole but the real interactions between system components are complex. This description ‘abstracts from’ the individual per-experiment services and applications and focuses on the common components of the CloudFlow Platform as presented in the following figure.

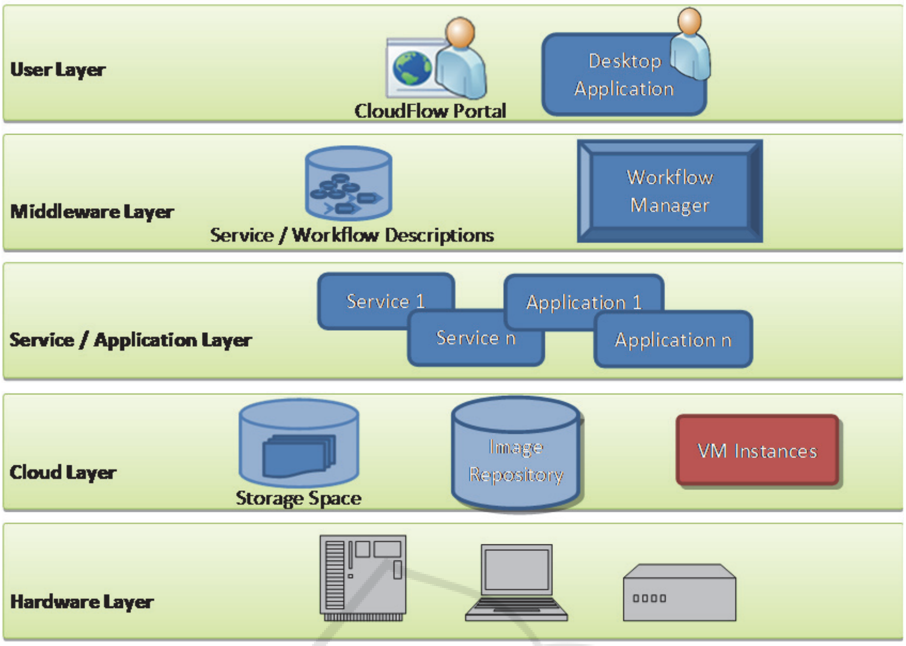


Fig. 2. The layer structure of the CloudFlow platform.

2.1 Cloudflow: Definitions

The following definitions are adapted to the CloudFlow project. The used terms may have a slightly different or wider meaning outside of this project.

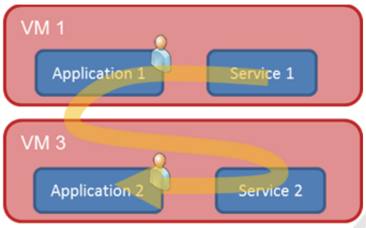
CloudFlow Platform	
	The CloudFlow Platform encapsulates all of the components illustrated in Figure 1. It comprises everything which is required by the described CloudFlow components to perform their tasks and to communicate with each other.

CloudFlow Portal	
	The CloudFlow Portal is a web site that serves as a user entry point to the CloudFlow infrastructure. It is a web-based client through which a user may log in and interact with the CloudFlow system. As such, the CloudFlow Portal provides a web-based Graphical User Interface (GUI) that allows activating other CloudFlow tools and applications using a standard web browser.

Desktop Application

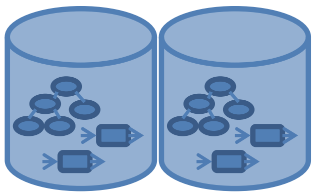
A Desktop Application is a program installed on a user's local machine that interacts with the CloudFlow infrastructure. It can be used as an alternative to the Portal.

Workflow



A workflow is a sequence of connected steps needed to be performed to achieve a certain work task. Every workflow step is either a service or an application. CloudFlow workflows consist of one or more applications and services. Workflows (as well as services and applications) have semantic descriptions and are executed by the Workflow Manager.
The main idea of this concept is to hide the complexity of data flows and internal communication from the user so that she/he can focus on the actual engineering task.
To further ease the use of workflows, pre-defined workflows will be created by system administrators in collaboration with experienced engineers and will be ready to use for end users. In the future, users will also be able to adapt pre-defined workflows depending on their individual needs using the Workflow Editor or to rely on an automatic assembly using semantic concepts.

Semantic Service / Workflow Descriptions



The machine-readable semantic descriptions of services, applications and workflows comprise the respective location, functionality, inputs and outputs. This kind of service description guarantees the compatibility between software from various vendors. The automated checking of semantic consistency and the inference of implicit knowledge are only two of many advantages offered by semantic service descriptions. In the future development, these will be further exploited, e.g., in the Workflow Editor.

Workflow Manager

The Workflow Manager is a CloudFlow component that automates the execution of workflows consisting of several services and applications and monitors their execution status. It hides the complexity of executed chains of services and applications by taking care of the data flow between the inputs and outputs of the single services and applications.

Workflow Editor

The Workflow Editor is a CloudFlow component that will allow users with the appropriate rights to specify new and/or edit/change already existing workflow definitions. The Workflow Editor backend will make use of the semantic service and workflow descriptions to enable a (semi-) automatic workflow creation/adaptation. It will provide a SOAP[1] interface, to which a web-based GUI will be connected that enables comfortable access to the Workflow Editor's capabilities via the CloudFlow Portal. The Workflow Editor is not yet included in the current state of development, but will be available for future experiments.

Service

A service is a piece of software / program that runs remotely on the Cloud performing computations.

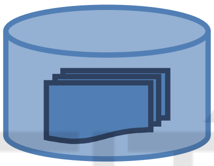
A service provides the computation results back to its caller. During its execution, it can, e.g., interact with the CloudFlow Storage Space or a dedicated data base. In CloudFlow, two types of services are distinguished:

- a **synchronous service** performs its computation before returning;
- an **asynchronous service** returns immediately and notifies the Workflow Manager using SOAP when it is done.

Services do not rely on user input during their execution, but may display their status to the user, e.g., through a small web page. Services will be made available as SOAP web services with a standardized interface and must provide a corresponding interface description in form of a WSDL[2].

[1] Simple Object Access Protocol
[2] Web Services Description Language

Application	
	Applications provide a graphical interface for the CloudFlow user to interact with a running workflow. The purpose of applications may range from simple web pages to let the user set parameters for the following services or receive (intermediate) output values to complex interactive visualization and even remote access to commercial software packages. Since the execution time of an application is user-dependent and will certainly exceed standard SOAP communication timeouts, applications use the same mechanisms as asynchronous services to interact with the Workflow Manager.

Storage space	
	Storage Space is disc space (physical or virtual) provided by the CloudFlow Platform that enables to store input, intermediate, and output data. Data from this storage space can be downloaded to a local machine by a CloudFlow user for archiving the data in company data bases or additional use in other standard applications.

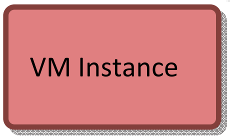
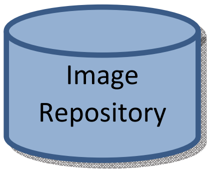
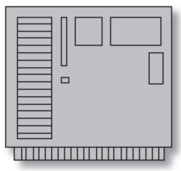
VM – Virtual Machine	
	Virtual Machines are used to run services on the Cloud. They contain one or more services. To start a virtual machine, its image is loaded from the image repository located in the Cloud layer and executed using dedicated virtualization software. In order to transparently allocate on-demand compute nodes for the execution of compute-intensive workflows, compute-resource-provisioning will be implemented for future experiments. This will provide abstractions independent from Cloud vendors for the CloudFlow Portal and Workflow Manager in order to bring up and shut down on-demand instances with the correct virtual machine for a given workflow execution.

Image Repository	
	The (virtual) Image Repository is a repository that holds images of all VMs that are available in the CloudFlow context. To deploy a service in the Cloud, a corresponding virtual image has to be created by the service provider, bundling the service executable with the needed environment. Usually, one starts with an image provided by the Cloud provider and installs and configure additional software (if any). The new image is stored in a database in the Cloud infrastructure.

Hardware	
	Hardware is the actual compute resource on which services are executed. We distinguish between Cloud hardware resources and HPC resources.

2.2 The Interplay of the CloudFlow Components

The next illustration (Fig. 3) shows the interplay between the main software components of the CloudFlow Platform during the execution of a workflow in a high-level schematic way.

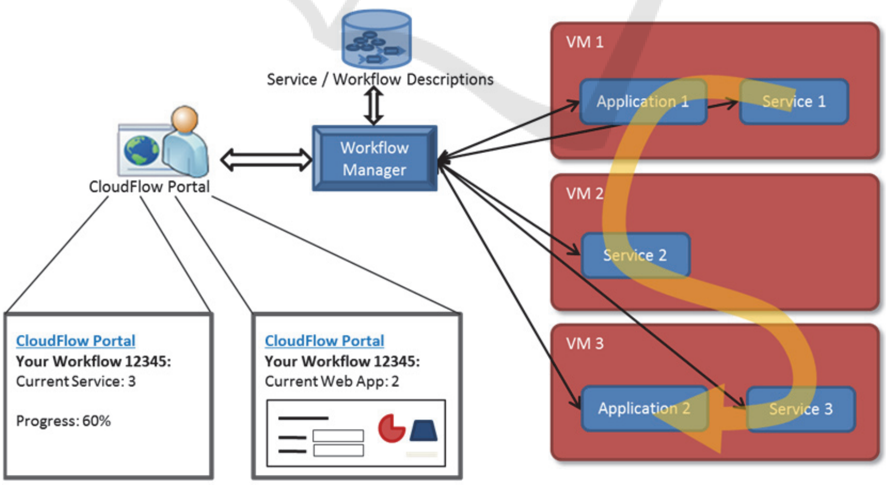


Fig. 3. The interaction overview of the main CloudFlow system components.

The Workflow Manager plays the central role of a broker to hide the complexity of executed chains of services and applications. It allows to invoke and to monitor the execution of services and applications, automating complex workflows that consist of many services / applications.

The Workflow Manager is able to start a selected workflow and to pass the needed input parameters. Then semantic descriptions of relationships between services and applications which take part in the ordered workflow are used to pass output values from finished services and applications to the later stages in the workflow. Asynchronous services have to provide a current state of computation progress on request during their execution. The progress status of the workflow can then be requested from the Workflow Manager and displayed to the end user. With the same mechanism, it is also possible for the Workflow Manager to pass the whole graphical user interface from an asynchronous service (in this case called an application) to the end user. At the very end of the workflow, its final results are stored by the Workflow Manager and can later be accessed by the user upon request.

All functionality of the Workflow Manager is available through a SOAP web service interface. It can then be accessed by user-friendly clients, as, e.g., the Portal. Other clients, such as Desktop Applications, are also possible.

Distinct services and applications run in separate Cloud environments and thus need the Workflow Manager as the centralized system to initiate and control the workflows in which they are integrated. Consequently services and applications have to implement a common interface that allows full compatibility with the Workflow Manager and with other services and applications from various vendors. The semantic descriptions of services, applications and workflows chosen by CloudFlow guarantee this compatibility and let the user select workflows without the need of specific expert knowledge for each of the services contained in a chosen workflow.

The CloudFlow software components aim at being neutral to Cloud providers and Cloud APIs. Commonly used functionality is implemented as separate services, hiding vendor specific APIs. The current implementation uses a mix of Cloud software components. For example, the commercial software vCloud is used for controlling virtual machines, while solutions from the open source project OpenStack are used for authentication.

With the CloudFlow Platform, engineers as the intended main end users are given a universal tool to configure, track and interact with expert software without any knowledge about its implementation. To complete a certain engineering task end users can select a suitable pre-defined workflow using the CloudFlow Portal and start its execution. In the future, using a Workflow Editor component currently under development, they will also have the possibility to create new workflow definitions or adapt existing ones.

The end user is only supposed to interact with the workflow at certain points, when its execution reaches an application. In this case, the user may for example be asked to provide additional input of domain specific configuration information which is not available as output from previously executed services in the workflow and cannot be specified in advance. Applications may also display intermediate output values or can even be interactive visualizations. Applications are implemented to run in a browser and can thus be displayed inside the CloudFlow Portal or in Desktop Applications.

Note that the current version of the Workflow Manager only supports services using a SOAP API, where all parameters are embedded in an XML document compliant with the respective SOAP schema. WSDL (Web Service Description Language) interface descriptions are used to specify the interfaces of services and applications. The machine-readable semantic descriptions also contain references to the information stored in the WSDL files of the respective services and applications, as for example their exact invocation endpoint.

3 CloudFlow: Hardware Layer

In this section we describe the current CloudFlow hardware infrastructure as provided by Arctur (HPC partner at CloudFlow).

3.1 Cloud Configuration

Arctur uses CentOS 6 distributions of Linux in its datacenters wherever possible. If Linux is not a possibility, then Windows Server 2008R2 or Server 2012 can be used. Arctur's goal is to reduce manual work to a minimum; therefore most of the server infrastructure is operated by means of the Puppet configuration management system.

VMware vCloud is used for Cloud services. On top of the actual hardware ESX 5.1 provides a hypervisor layer. In the application layer different operating systems can be used by the consumer. Amongst the most used ones are the Ubuntu and CentOS distributions of Linux followed by Microsoft Windows Server solutions.

3.2 Hardware Configuration

Arctur's systems to run production tasks in the Cloud can be categorized as:

- hosts for virtual machines,
- hosts to provide storage over iSCSI and
- hosts covering infrastructure support roles.

They are generally equipped with dual core Xeon 51xx and quad core 54xx CPUs. iSCSI runs over 1Gbit Ethernet, provided by 3com 4500G switches.

The Arctur HPC system is based on an IBM iDataPlex solution. Each of the 84 nodes is equipped with two Xeon X5650 CPUs and 32GB of memory. They are connected with a high speed low latency InfiniBand network, used mainly for MPI communications between nodes. This provides for 10TFlops of computing power. They are also connected with Gbit Ethernet for management and another separate Gbit Ethernet for the parallel file system Lustre. The Lustre system is aggregating over 100TB capacity and 4.5GB/s throughput.

Head node to the HPC cluster is an IBM machine with the same CPUs as the compute nodes but 48GB of memory and more local storage.

One node in the system is equipped with an NVidia GPU. Due to the configuration of the InfiniBand network this GPU node can be reached by every node in the

HPC system, thus enabling a boost in performance if the application is able of taking advantage of CUDA capabilities.

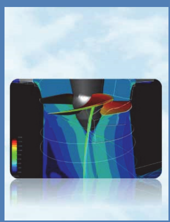
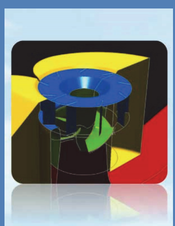
The HPC system/cluster is running CentOS6 with usual HPC add-ons (OFED, MPIs, etc.). Queuing and resource management is implemented with Torque PBS + Maui.

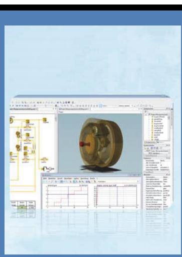
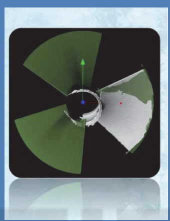
User applications and software are installed and configured on a pre-experiment basis during the testing and debugging period. Therefore the software stack is constantly being adapted to current demands. The software configuration is primarily left to the actual users to configure as they need. If the configuration is needed on an administrative level, a team of HPC system administrators supports or independently deploys the software solutions that are needed.

4 CloudFlow: Experiments

The CloudFlow Platform, with its current infrastructure and six internal experiments, consists of dozens of services and applications. In this section there is a brief explanation of each of the initial experiments.

Experiment	Summary
1. Computer Aided Design (CAD) in the Cloud 	Parametric design of products in CAD has enabled the industry to parameterize classes of their product shapes thus significantly increasing productivity. However, standard parametric design functionality in CAD systems does not cover all product classes well. This is especially true for products with a sculptured shape. For such products tailored design applications are often the way to go, however, these are in general expensive as their market is small, and distribution through traditional vendors limited. Supporting such systems on a big spectrum of hardware platforms is prohibitive. On the other hand, selling services for parametric CAD in the Cloud will remove the complexity of traditional distribution and focus the support only on the hardware of the Cloud platforms used.
2. Computer Aided Manufacturing (CAM) in the Cloud	Although commercial CAM software offers a wide spectrum of functionality, some companies have specific machines, processes and requirements that are not covered by standard solutions. To solve these challenges either expensive niche software has to be purchased or company specific CAM technology has to be developed. The Cloud allows services to be offered on the global market targeting niche CAM needs. CAM-based assemblies are always specific and are designed on demand. The assembly depends on a CAM type (cylindrical, glo-

	bic, and planar), a set of parameters, and one or more movement laws. The result will be the ISO file for machining the part to be produced according to the customer machine (Post Processing).
3. Computational Fluid Dynamics (CFD) in the Cloud 	The proposed workflow starts from the initial and released CAD representation of a 3D geometry. The mesh generation service will be used to generate the mesh, which will then be input to the CFD solver running on the Cloud, possibly on a different infrastructure. The mesh generation and solver service on the Cloud run in a transparent way for the user. The process will in many cases need to be run iteratively to reach the optimal design. For this experiment, the meshing setup and CFD setup are carried out on the user's local machine. The monitoring of the solver convergence will be through a web interface, either through a dedicated thin client or through a web browser. In this experiment, small and medium sized problems are tackled. CAD input files will typically range for a few megabytes to tens of megabytes. Meshes and CFD results are expected to range from tens to hundreds of megabytes.
4. Product Lifecycles Management (PLM) in the Cloud 	The experiment will implement the PLM support of a basic analysis process: design, mesh generation, loads definition, analysis and post-processing. These steps produce several 3D-models of the analyzed product: the CAD model, the meshed model and simulation result models for various load cases. This experiment will focus on giving the user easy, fast and useful access to these graphical models for visual inspection. Visual inspection is given priority in this experiment as one of the most efficient methods of verification and validation.
5. Systems Simulation in the Cloud	The experiment will implement CloudFlow services that allow to define and execute systems simulation tasks and to analyse the simulation results. The simulation model describes an electro-hydraulic power plant, including surge tank, distributed pipe with right distribution of pressures and a simple curve-based model of a Kaplan or Francis hydraulic turbine. This

	system model is usable for pre-dimensioning of components and the test of critical use scenarios as for example full load-shutdown to avoid water-hammer effects. These cases need time-consuming parameter variations due to the performance-disturbing distributed pipe. Additionally system models are used for the examination of rarely occurring cases of damage (e.g. extreme use situations such as low temperatures). The result of this experiment will be a service interface which is independent from a systems simulation tool vendor. The implementation with SimulationX provides the proof of concept.
6. Point clouds vs CAD in the Cloud 	The power efficiency of water turbines is strongly related to the shape of their blades. The CAD-model and the models used for calculating the power efficiency do not exactly represent the blade shapes produced. A turbine and its blade last decades. During their lifetime the blade shape is worn by silt and sand. Under some circumstances cavitation can severely damage the blade surface. The application experiment thus serves two purposes: • Comparing the produced turbine blades with their nominal shape (CAD-shape). • Checking older turbines and their blades for wear and deciding on the need for repairs and upgrades.

5 CloudFlow: Business Aspects

In addition to the potential business models for each of the software vendors CloudFlow has analysed possible concepts to be validated for the CloudFlow Platform as a common aggregator of solutions operated by the HPC organisation.

5.1 Value Proposition

<u>Product name</u>
CloudFlow Engineering Software Platform.

<u>Most Relevant Technical Characteristics</u>
CloudFlow Platform is the aggregation portal of all software applications being part of the CloudFlow project. It will be automated to the point that the customer can easily and seamlessly work with the different software tools.

Differential Aspects in Front of Most Important Competitors
CloudFlow is workflow-based. The differential and unique value of CloudFlow in front of competitors is based on the workflow approach to the use of the different applications. It is not just the aggregation of software tools or a simple marketplace, it is the seamless and transparent combination of interoperable services.

5.2 Distribution

Distribution Channels
The distribution of the platform should be done combining the natural and fundamental Internet approach together with the expert support of the software vendors. This two-fold method should add a synergistic effect for the customer.

Marketing
Marketing should be covered addressing 4 topics: (1) Internet marketing, (2) SEO - Search Engine Optimization-, (3) Specialised Media and (4) traditional marketing from software vendors.

5.3 Customer Relationship

The workflow management should be as automatic as possible thus facilitating the independent operation of the CloudFlow platform. In any case, the platform should give customers the option to get in touch with experts by means of a hot-line or any analogous mechanism. Therefore, CloudFlow should have easily accessible experts for each software tool, but also for the HPC and cloud infrastructure and for the workflow process management itself.

5.4 Customers

The target customers of the platform should be the same of the detected customers for the individual software tools. On top of that, sectors and industries making intensive use of workflows combining different services within CloudFlow should be identified.

5.5 Revenue Streams

Incomes
In front of the customer, CloudFlow should be seen not only as a single entry point to all services or just as a marketplace. On the contrary, CloudFlow should be perceived as a unified common system with a centralised payment procedure. The customer should clearly know what he gets in return for the money he is about to pay. We can compare and study in detail three payment methods: (1) Prepaid model, (2) Actual usage fee and (3) Subscription fee. This is the transparent approach to the customer, behind the unified payment system the shareholders of the platform should internally

distribute the money following a common approved pattern.
The prices may vary depending on the frequency/loyalty of each customer and/or the number of services to be operated.
Incomes depend on: (1) Software application, (2) Computing power, (3) Storage resources. In addition to this transparent part, the user should also be charged for (4) Portal use, (5) Internet communications if there is any singular demand on that issue.

5.6 Key Resources

Personnel
The key resources in the CloudFlow Platform case are:

- Software applications, HPC and Storage resources. They are the key services within the CloudFlow Platform.
- Portal and Internet. It is the basic distribution channel for the cloud services.
- Communication. It is sometimes a critical factor (private channels, direct links, special services).
- Supporting personnel. System and portal support, and experts assisting customers online.

5.7 Key Activities

- Portal operation and administration. Including charging, billing and internal distribution of funds.
- Security.
- Supporting services. Including experts from all domains (software, HPC, workflows...).
- Software upgrading.
- Marketing, commercialisation and exploitation.

5.8 Key Alliances

Key alliances should cover on the one hand the basic commercial relationship between the software providers and the HPC provider. In addition to that, the organisation in charge of exploiting the Portal should be a key ally, as well as the telecommunication provider.
In CloudFlow the HPC provider and the Portal administrator is the same organisation.

5.9 Cost Structure

The main costs involved in the operation of our CloudFlow Platform are those related to:

- Hosting. Including renting space.
- Operating costs. Internet communications, electricity, system support, portal support, services support.
- Upgrading costs.

6 Conclusions

Traditionally, the European manufacturing industry is characterized by innovative technology, quality processes and robust products which have leveraged Europe's industrialization. However, globalization has exposed Europe's industry to new emerging and industrialized manufacturing markets and the current economic challenges have decelerated the internal boost and investment, respectively. Hence, new ICT infrastructures across Europe need to be established to re-enforce global competitiveness.

CloudFlow has the ambition to provide a Cloud Computing infrastructure based on existing technology and standards that allows SME software vendors to offer current and future customers (being it SME or bigger companies) new cloud services along and across the engineering and manufacturing chain - even vendor independent.

CloudFlow covers Computer Aided Design and Manufacturing (CAD/CAM), Computer Aided Engineering (CAE), Computational Fluid Dynamics (CFD) including pre- and post-processing, simulation of mechatronic systems (Functional Digital Mock-Up – FDMU) and Product Lifecycle Management (PLM) including data archival.

CloudFlow will enable Users from different engineering disciplines to manage large amounts of heterogeneous Data in an interoperable manner, allowing for making results available as a standard Archival Information Package (AIP) both for documentation and for reuse. CloudFlow will provide 'single point of access' to computational (simulation) and data management Services on high-performance clusters (HPCs) and the possibility to use services in Workflows, i.e. execution of chains for services or services-in-a-loop in a synchronized and orchestrated manner, as well as to use services in a cooperative and collaborative manner, e.g. for co-simulating mechatronic systems, for joining up CAD/CAM with flow simulation of blades for turbine machines. Thus, it does decisively go beyond just providing individual data exchange or singular compute services.

CloudFlow will establish a Competence Center from the very beginning to call for Application Experiments to handle proposals by the CAD/CAM, CAE, Systems and PLM community and their execution on the CloudFlow infrastructure. There will be three waves of experiments, the first wave starting in the first phase of the project with experiments from the core partners is already in place. The second and third waves will be open to the community and will call for increasingly complex and challenging use cases, especially on engineering and manufacturing services and workflows.

The whole CloudFlow system is built in a multilayer architecture to separate functionalities. It consists of 5 main layers, which may contain one or more system components. From the end user perspective all the layers are seen as a whole but the real interactions between system components are complex.

At the very top in the system's hierarchy there is the User Layer. Its main task is to provide an entry point for the user of the CloudFlow system. It contains the CloudFlow Portal and desktop applications (adjusted to cooperate with the CloudFlow infrastructure) that enable users to choose, configure and control the execution of workflows. They also give the possibility to interact with applications when it is necessary.

To enable the seamless integration of services and applications from different software vendors, the Workflow Management Layer was designed. This layer contains applications and storage space to automate the management and maintenance of the user's workflows.

The Service / Application Layer is the most important part of the system from the end user's view. It provides expert software that can be used by the end user. This software is divided into separate services and applications, which offer different functionalities and can be efficiently connected into workflows to suit individual customer's needs.

In between the Service / Application Layer and the Hardware Layer, the Cloud Layer is implemented. Its role is to enable scalable access to the hardware resources. It provides access to the storage space, where all the user and temporary file can be stored, a repository with images of Virtual Machines (VM) and the VM instances, in which the three uppermost CloudFlow layers run.

The whole CloudFlow system uses the hardware infrastructure provided by Arctur. Its cluster structure enables to assign the hardware resources in a very flexible way, depending on the actual needs.

The infrastructure will be expanded and improved in the next project phases as CloudFlow will conduct two Open Calls for external experiments investigating the use of the CloudFlow infrastructure in new and innovative ways, outreaching into the engineering and manufacturing community and engaging external partners. Each of these two Open Calls will look for seven additional experiments to gather experience with engineering Cloud uses and gaining insights from these experiments.

CloudFlow is striving for the following impacts: a) increasing industrial competitiveness by contributing to improve performance (front-loading, early error detection, time-to-market, …) and innovation (co-use of models, early virtual testing), and b) improving in innovation capabilities by enabling more engineers to gain insights and to create innovation by accessing 'new' tools and easing the use of Cloud Infrastructures.

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