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Article in Concurrent Engineering · August 2017
DOI: 10.1177/1063293X17724848

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A cloud platform for space science mission concurrent design

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Abstract
Using concurrent design methodology, the duration of space science mission in conceptual design phase can be shortened. This approach requires hardware and software resources to support, such as professional design tools and concurrent design environment. Except for the professional groups, the general researchers such as teachers and students have no chance to access these resources. Nowadays, more and more researchers distributed in different locations join into the space science research. The need for an open concurrent design platform offering design tools and data sharing environment has increased. This article presents a Cloud Platform of Concurrent Design for Space Science Mission. This Cloud Platform of Concurrent Design for Space Science Mission uses the idea of Software as a service, in which five design and analysis tools are offered as services to satisfy the basic requirements for space science mission concurrent design in conceptual design phase. This cloud platform provides the access to space science mission concurrent design for expert and non-expert users using a thin client of web browser. This article presents the platform architecture of the Cloud Platform of Concurrent Design for Space Science Mission and five software offered as services. The services include spacecraft conceptual orbit design, structure design, payload coverage analysis, data transmission analysis, and virtual community. And the basic cloud service (computing and storage) is also briefly introduced. It is described in detail how these services can be leveraged by users to do the concurrent design for one space science mission.

Keywords
cloud platform, Software as a service, space science mission, concurrent design, conceptual design phase

Introduction
Space mission design is a complicated process, which requires systematic methods to support. The design process involves numerous engineers from different disciplines working on independent components (Shekar et al., 2011). The design process has the characteristics of coupling and iteration, and it is a negotiation process. One of the main goals of a conceptual design study is to explore many feasible solutions and select the best for further analysis in later design phases (Pahl et al., 2007; Ullman, 1992; Ulrich and Eppinger, 2000). Using the classical approach needs 6-9 months. It may be incompatible with today’s drive towards a shorter time-span from concept to flight. In order to reduce the iteration times and shorten the duration, concurrent design methodology was introduced into the conceptual design phase. Concurrent design is a process where a product is designed through the collective and joint efforts of domain experts (Safavi et al., 2015). Concurrent engineering has evolved into a crucial supporting mechanism for space mission design and analysis during the early project phases (Akhundov et al., 2016). Space mission concurrent design uses the concepts and methods of concurrent engineering to scientifically and efficiently support space mission projects demonstration. Systematic research on space mission concurrent design will help to shorten duration time (Rocca and Tooren, 2007), to improve the level of project feasibility studies, and to implement scientific argumentation.

In recent years many institutions have established their own concurrent design facilities. The collaborative engineering environment evolving within the National Aeronautics and Space Administration (NASA) is a capability that enables the Agency’s engineering infrastructure to interact and use the best state-of-the-art tools (Monell and Piland, 2000). For example, the NASA/JPL(Jet Propulsion Laboratory) Project Design Center (PDC) is for conceptual mission design. NASA Goddard Space Flight Center (GSFC) has used its Integrated Mission Design Center (IMDC) to perform more than 150 mission concept studies (Karpati et al.,...
2003). Since 1998, the European Space Agency (ESA) has been developing preliminary studies for new space missions using the Concurrent Design Facility (CDF) (Bandecchi et al., 2000). ESA has adopted concurrent design methodology for the early stage of the design of space systems, and aims to promote the use of this approach, also for more advanced design phases, in the frame of the European Space Industry. In China, a CDF of National Space Science Center (NSSC)-Chinese Academy of Sciences (CAS) is built to support the conceptual design and assessment for Chinese space science missions (Deng et al., 2013).

The assessment studies performed have shown the benefits of using concurrent methodology. For example, in ESA CDF, the design phase was completed in an average period of five weeks (Bandecchi et al., 2000). But actually this approach requires hardware and software resources (Domizio and Gaudenzi, 2008). In these facilities, many professional design and analysis software are provided to scientists and engineers.

Due to the increasing need for exchanging knowledge, modern design projects are even more structured to work with virtual distributed teams that collaborate over computer networks (Dutra et al., 2010). Some virtual design system ideas have been put forward. For example, the Virtual System Design Environment (VSDE) is a development project managed by NASA GSFC’s Advanced Engineering Services and Environments (AESE) office (Mapar et al., 2001). The mission of AESE is to revolutionize GSFC’s engineering processes to increase science value and aim to facilitate the design for scientists in different locations.

But all these facilities, neither the reality facilities nor the virtual design environment, are designed and open for the public researchers, only for the special groups and special missions. With the development of space science and exploration technology, more and more people pay attention to and join into the space science research group. Especially some relative professors and students are emerged to make new creative ideas. But they have no access to resources like professional design software or concurrent facilities enabling them to share the data. They need a totally open platform to supply these services.

An innovative idea was given to build a service-oriented space science mission concurrent design cloud platform (Yang, 2012). Then, a lot of work about technical development and verification has been done to make sure this approach is available and flexible (Song et al., 2015).

The article presents the Cloud Platform of Concurrent Design for Space Science Mission (CP-CD-SSM) that offers the software resources as services to the public. In the following section, the platform architecture is shown. Then, five software as services offered are introduced in detail, which can satisfy the basic requirements for space science mission design and analysis in conceptual design phase. After that, collaboration strategy is described. Finally, the interests of the presented research work are declared.

**Platform architecture**

The CP-CD-SSM is a platform offering space science mission collaborative design application services on a cloud infrastructure. The concurrent requirements of the cloud platform are as following. Firstly, some design and analysis tools in conceptual phase are offered as services, and the group members of each mission can do concurrent design in a virtual environment. Secondly, the data will be shared and synchronised in real time. Thirdly, these services are distributed by the CP-CD-SSM, Chinese Academy of Sciences (CAS). The data will be stored in cloud storage. In order to satisfy these requirements, the cloud platform was designed to provide a virtual collaborative environment and a set of design and analysis software that allow users to access the applications through a thin client interface.

The CP-CD-SSM adopts the idea of Software as a Service (SaaS), providing five software services: spacecraft conceptual orbit design service, spacecraft conceptual structure design service, payload coverage analysis service, data transmission analysis service and virtual community service. This cloud platform is implemented in the cloud server center of CAS, which provides the hardware environment and automatically allocates computation and storage resource according to the requirements.

The architecture of the CP-CD-SSM mainly consists of three layers shown in Figure 1, which are application layer, application service layer, and infrastructure layer.

Application layer is realized by HTML5, CSS3 and JavaScript, and needs to run in the browsers supporting HTML5. This layer implements the pages of task management, model operation, concurrent operation bulletin and data calculation. It also provides the control functions of task management, instruction parsing, model design, etc. Besides, this layer establishes a set
of information management interfaces for exchanging data with application service layer.

Figure 1. The system architecture of the cloud platform.

Application service layer hosts a collection of services that perform all the operations required by applications. This layer consists of system services and web socket services. System services provide services to support the functions in application layer and these services are published on the network. System services receive the requests from the application layer and return the processed data. Web socket services also establish a full duplex channel which is realized by web socket protocol. Through the channel the data can be exchanged between application layer and application service layer.

Infrastructure layer provides access to the database, file system and the cloud storage resources. The physical infrastructures are belong to and managed by NSSC-CAS. The platform, in infrastructure layer, has the API to use virtual machines and the cloud storage resource. The users’ data have two types of storage, most design solutions are stored in files, and most operation instructions are stored in database. These data are all stored in cloud storage.

The CP-CD-SSM adopts web service technology to realize cross-platform integration of the resources on the Internet and solves the problem of the integration of heterogeneous resources. Besides, B/S architecture is applied in the system, which brings the advantages of web applications and avoids the trouble of installing and updating application programs.

The data exchange, reading, translation, and viewing, especially in a remote mode, are very important (Eynard et al., 2005). Numerous mature technologies and standards format, such as VRML (Kan et al., 2001) or Java3D (Tay and Roy, 2003) for 3D viewing can be used in web-oriented applications. In recent years, as the major browsers start to support HTML5 and WebGL, 3D concurrent design finds a new direction in web applications (Evans et al., 2014). WebGL technique as a web standard created to display 3D graphics is used in the cloud platform. It makes use of
the HTML5 Canvas element to generate graphic dynamically from script code. So there is no need to install plug-ins in the web browsers. We applied Three.js as a 3D rendering engine which is a third-party open source library based on WebGL. With the basis of the 3D rendering engine, the system creates a 3D design scene include camera, lighting and other objects in the browser.

![Diagram of cloud platform services interface](image)

**Figure 2. The cloud platform services interface.**

**Software services**

Cloud service reflects the ideas that distributed resources can be integrated for one task and integrated resources can be distributed for service (Zhao and Zhu, 2016). Three pillars of cloud computing solutions are delivered to users: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure/Hardware as a Service (IaaS/HaaS).

SaaS platform is not only a development platform but also a resource platform. In the scheme of SaaS, all data and software can be used as services. These services represent as API or applications provided for users (Satyanarayana, 2012).

The CP-CD-SSM uses the solution of SaaS, and provides five software as application services: spacecraft conceptual orbit design, spacecraft conceptual structure design service, payload coverage analysis service, data transmission analysis service, and virtual community service (shown in Figure 2). These services generally can satisfy the basic requirements for space science mission concurrent design in conceptual design phase. The CP-CD-SSM is a sub-cloud of the space science cloud of NSSC-CAS.

**Spacecraft conceptual orbit design service**

Spacecraft conceptual orbit design service is offered to do earth-centered or other planetary-centered orbit design and simulation. After logged in the cloud platform via a web browser, the users can leverage this service as a spacecraft orbit design software.

For a new mission, a scenario is an instance, and satellites, sensors, stations are the objects in the scenario. The two-body and J2 model are used as orbit propagation models. By dragging the mouse to change the key parameters of the orbit, the user can quickly build the spacecraft orbit or change the orbit parameters. As shown in Figure 3, the user interface of spacecraft conceptual orbit design service mainly includes menu zone, objects browser zone, and 3D window show zone. Through new menu bar, we can create a new scenario and select one planet as the viewpoint, and several coordinate systems are offered to
switch the view point. The planets include Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The coordinate systems of each planet include VVLH, J2000, inertial coordinate system, and so on. Especially for Earth, the coordinate systems also include magnetic coordinate system. For the scenario, heliocentric ecliptic coordinate system is also offered.

For one scenario, we can create a new satellite by new menu bar. The steps for orbit interactive design are as following:

1) Select the center planet in menu bar. This planet will be the center of the spacecraft orbit.

2) Create a new satellite by “new” menu bar. A new satellite will be showed in the scenario.

3) Click the orbit in the 3D window, six special points will be marked in this orbit. These six points are feature points to adjust the perigee, apogee, inclination, argument of perigee, right ascension of ascending node, and true anomaly. A bidirectional arrow shows around each special point. It is showed in Figure 3.

4) By selecting the special point arrow and dragging the mouse, the orbit in 3D window will change simultaneously. And the parameter value of the orbit will be dynamically shown in the bottom-right zone. Click the “start” button in menu bar, the orbit simulation will show in the 3D window.

5) Click the save button by “new” menu bar, and the scenario will be saved in the cloud storage. If you would like to download the data in local computer, “save as” button can be used.

Each operation in the interface by users is one application service request. The application service layer will perform relative function like data fitting, orbit prorogation and model simulation. The response will be returned as feedback to the user interface. These operators are convenient for the users. Spacecraft conceptual design software service is managed from a central location, and delivered to many users.

**Spacecraft conceptual structure design service**

Spacecraft conceptual structure design service is offered to quickly assemble one spacecraft. The structure model repository provides many models as design basis. It contains payload models, satellite bus platform models, rocket models and common models. By dragging the mouse in the scene or modifying the value, the user can modify the components’ parameters, such as size, rotation angle, mass, etc. A variety of operators are offered, such as composing, separating, absorbing, etc. The user interface of spacecraft conceptual structure design mainly includes menu zone, objects browser zone, model repositions zone, 3D window show zone, as it is shown in Figure 4.
All operators are offered in the menu zone, which include move, rotation, zoom, combination, separation, adsorption, alignment, etc. The parameters modification, object list view and submit operation all can be gotten in the menu zone. The reposition models include five kind of models that are basic models, payload, satellite bus, rocket and extensible models. The basic models include sphere, cylinder, cube, etc. The satellite bus model includes 3-aix stabilized bus, spin stabilized bus, re-entry module, etc. The payload model includes sun sensor, star sensor, camera, onboard computer, solar-panel, etc. The rocket model includes CZ-2, CZ-3, etc. These models can help us complete one satellite structure design process. One 3-axis stabilized satellite is an example, the operation steps are as following:

1) Create a new spacecraft by “new” menu bar. The spacecraft will be shown in objects browser zone.
2) Select a 3-aix stabilized satellite bus from the models zone. Once we have selected the model, the model is shown in the 3D window. We can see the coordinate axis of this object. The size can be modified by dragging the mouse along the axis. As it is shown in Figure 5.
3) After all the components have been added, we can use absorption, combination and separation operations to assemble. The absorption operation is the key operator to guarantee all parts accurately assembled, by which components can become one part of the selected body through the surface. This operation is completed by two sub-steps. The first sub-step is to select the surface of the body to be absorbed. The second sub-step is to select the surface of the substance. After absorption, the components will be one combination. Then we can use the move operation to adjust the components to the accurate position. As it is shown in Figure 6.
4) After that, by rocket model, we can judge whether the satellite size is suitable for the rocket.
5) Finally, click the save button in menu bar, the scenario will be saved in the cloud storage. If data need to be downloaded in a local computer, “save as” button can be used.

For this service, we applied Three.js as a 3D rendering engine which is a third-party open source library based on WebGL. With the basis of the 3D rendering engine, the system creates a 3D design scene include camera, lighting and other objects in the browser. The 3D design scene gets the geometric model parameters and material parameters of the components by loading the “.obj” and “.mtl” files. The model repository was built up by loading model files (“.obj” and “.mtl” formats), and the models can be designed by 3D modeling software such as 3ds
In this way, a steady stream of models can be imported into the repository.

![Figure 5. Interactive structure operation.](image)

![Figure 6. Assembling operation process.](image)

**Payload coverage analysis service**

Payload coverage analysis service is a payload observation time analysis tool. The coverage analysis mainly includes earth observation and sky observation. The coverage analysis models are based on geometric relationships among payload pointing direction, boresight angle and objective’s position. The payload, as a sensor, could be attached to a satellite whose orbit and attitude parameters have been configured. Payload pointing direction is determined by satellite platform attitude and the relative pointing in satellite body coordinate system. Through platform attitude maneuver control, payload pointing direction and the boresight will be changed correspondingly. For earth observation, the point objective could be selected on the earth. Using the coverage analysis service, the coverage time would be calculated and the results would be returned and shown in the interface. Moreover, the coverage statistic, from one payload to multiple earth objectives, or from multiple payloads to one earth objective, could be gained. For sky observation, the point source objective in the sky could be set as right ascension and declination in celestial coordinator system. In the same way, the point source objective coverage time could be got. Furthermore, for the regional objectives described as a circle or a square, the coverage models are also suitable.

The user interface of payload coverage analysis service is shown in Figure 7. The payload, as a satellite sensor, is the main equipment to achieve the scientific goals. We can set the sensor parameters for one payload. Prior to this, the satellite orbit and attitude have been defined, such as three-axis stabilization to the earth, or spin stabilization to one fixed direction. The observation objects include earth point objects, sky point objects, and sky area objects. By coverage analysis, we can calculate a number of objects covered by one payload sensor, and calculate one object covered by some payload sensors. The simulation service is deployed on the server, and the simulation results will be returned and shown in the results zone.

**Data transmission analysis service**

Data transmission analysis service is an access time analysis and communication link budget calculation tool. In order to satisfy the data downlink requirement, data transmission analysis service could be used to estimate each ground station’s access duration and downlink budget. The downlink transmitter could be configured for the satellite of the mission. The candi-
date ground stations could be selected from the database. Subsequently, the minimum elevation and G/T of each ground station would be gained. Using the service, the ground station access time and feasible downlink data rate will be calculated. By comparing the results of different ground stations and modifying the onboard transmitter capacity, the recommended ground stations and onboard transmitter capacity would be determined. Figure 8 shows the user interface of data transmission analysis service. We can select the ground stations and determine the stations antenna parameters. By access analysis, we can calculate a number of stations accessed by one satellite, and calculate one station accessed by some satellites. The simulation service is deployed on the server, and the simulation results will be returned and shown in the results zone. By communication link budget calculation, the link quality can guide on-board equipment design and ground station selection.

Figure 7. User interface of payload coverage analysis service.

![User interface of payload coverage analysis service](image)

Figure 8. User interface of data transmission analysis service.

**Virtual community service**

The above services are for individuals, and are leveraged as isolated software. Complementarily the virtual community service is mainly objective to the group and especially for space science mission concurrent design. For one innovative space science mission, the team leader can leverage this service to create a new virtual community environment. After that, all the members can join in and enter this virtual community. On the one hand, team members chat via instant mes-
sages and share working data, just like in a reality facility. On the other hand, those services are integrated in the virtual community that includes spacecraft conceptual orbit design, structure design, cloud storage and other analysis services, such as data transmission analysis and view analysis of payload field.

Generally, the process of concurrent design for one space science mission mainly contains spacecraft conceptual orbit design, spacecraft conceptual structure design, payload coverage analysis, and data transmission analysis. This process will be repeated iteratively until we get the ideal solution. It is shown in Figure 9.

In the virtual community, the members have no time and region limitation, so they can effectively carry out collaborative work. Throughout the conceptual design of one space science mission, there is a process which engineers will follow. The mission requirements, the baseline and interface should be defined at first. All the tasks of the process will be distributed to the responsible engineers. During the process, some design and analysis services will be requested as needed. And the determined solution or some results will be submitted as system baseline, e.g. the orbit of the satellite, the selected ground stations. Once the design solution is determined, the data will be submitted and saved as a new version to update the system baseline status. At the same time, the data with version information will been synchronized and shared in the group. The following is an example for a group to use the virtual service.

1) Firstly, the team leader of the group logs in the cloud platform. As a mission sponsor, he will create a virtual community and organize a group for this mission. All members ID will be added into the group list by the team leader. When other group members log in the platform, they will accept the invitation and join the group, or they can reject the invitation. Thus, a virtual community for the new mission has been set up. It is shown as Figure 10.

2) Then, after one mission has been created, every member in the group can enter the virtual community and start to concurrently design in the same scenario. The user interface of the virtual community is shown as Figure 11. Exactly, this service integrates the above design and analysis services. In addition, virtual community service should guarantee the data synchronous and consistent between all the members. The interface mainly included menu zone, objects browser zone, 3D window show zone. According to the process of concurrent design, the members collaboratively work step by step. Firstly, mission analysis and spacecraft orbit and structure will be designed. Figure 12 is an example of collaborative structure design. Then, payload coverage and data transmission analysis will be implemented to demonstrate the feasibility of the solution. During the process, everyone can modify the solution and update data is in real time.
3) Finally, the data will be saved in the cloud storage, and the data also can be downloaded to be saved in the local computer. Next time when we log in, we can find the mission in my tasks and can enter this virtual community again.

For this service, data sharing, real-time collaboration and data consistency are challenging but very important. The corresponding strategies are described by the next section.

![Figure 10. Set parameters and organize the group.](image)

![Figure 11. User interface of virtual community service.](image)

**Cloud storage service**

Cloud storage solutions provide users with various capabilities to store and process their data in third-party data centers. This service enables users to access the cloud platform using a web browser regardless of their location or what device they use. Cloud storage is a model of data storage in which the digital data is stored in logical pools. The physical storage spans multiple servers, and the physical environment is owned and managed by NSSC-CAS.

**Collaboration strategy**

**Data sharing and real-time collaboration strategy**

Data sharing and real-time collaboration can be described as one time point, one scene for every user (Saito and Shapiro, 2005). Real-time collaborative system should guarantee the data of every user is consistent. Besides, a rapid response to users’ actions is important. The quality of the real-time is mainly influenced by network delay which is uncertain on the internet. Network delay is an objective reality which
cannot be removed from the system level. In general, online games require a very high performance in real-time synchronization. But the requirement of real-time performance in space science mission is more tolerant, and can be satisfied in an average network environment by a data replication strategy described below.

During the concurrent process, we take the user who launches the concurrent task as the sponsor, and others as participants. The storage of the task data is in three forms, i.e., database, cloud storage, and file system. During the whole process, every user maintains a contemporary local data copy of the share scene, the procedure of collaboration is implemented by sending serialized message of operation. In order to achieve consistency of the task, the consistent maintenance of the contemporary local data copy in every user is required. That is to say, the local data copy is modified by the user’s operations directly, so that the network delay will not affect the response time of the local operations. Once the task finishes, the sponsor will conduct a saving operation. Then according to the local scene data of the sponsor, the scene data will be written back into the three storage systems. Therefore, writing operation only involves one single user (sponsor), the storage layer of the platform has no relevance with the consistency problem.

In order to guarantee every user to see the same design scene, the local data copy for each web client needs synchronous update. After one user executes an operation in the mission scene, another web client automatically makes the same operation in its own scene just like an ‘imitator’.

Data sharing and real-time collaboration maintenance include three steps: 1) Once the user finishes an operation, the operation parameters will be sent to the server. 2) The server receives the updated parameters, then broadcasts to other users. 3) The other users receive the broadcasted instruction, then do the same operation immediately. In this way the data of each web client can be kept consistent. The replication strategy of operation instructions has been verified to be valid for data sharing and real-time collaboration.

Figure 12. An example of collaborative structure design for three users.

**Data locking**

However, data replication strategy brings a problem. That is how to keep distributed data copies synchronized, especially when more users operate the one scene simultaneously. When two or more users operate the same component in the design scene, a logic conflict will appear. To avoid the conflict, there are two methods widely used: optimism methods and pessimism methods (Mowafi, 2003). We prefer the pessimism methods that only allow the designer who occupies the component to operate it. So the data locking strategy is put forward to avoid the potential conflicts between several operators at the same time (Tan and Zhang, 2009).
The server and each web client keep a state parameter list to record the states of the components in the scene. Each component has two states that are locked state and unlocked state. The initial state of each component in the scene is set to be unlocked. When one user selects an unlocked component and does the operation, a lock request for the component will be sent to the server firstly. If the state of the component on the server stays in an unlocked state, it will be changed to locked state and the component is occupied by the user. At the same time, the server will send the lock instruction to other users immediately, other users will not be able to use this component. In this way, only one user has the operation right at one time. When one operation is finished, the web client will inform the server to change the state to unlocked, and then other users have the right to operate it. While a component is occupied by a user for a long time, the starvation issue will occur. Consequently, while waiting users click this occupied component, the component in the interface of user who occupy it will be highlighted in order to inform the occupier to finish his work about the occupied component soon.

The most common way of collaboration is to distribute a relatively independent design task to one user. Considering the number of the team members for one space science mission is generally dozens, it is rare that thousands of concurrent jobs compete for one busy exclusive component. Therefore, this data locking and data replication strategy is feasible for space science mission concurrent design.

Conclusion and future works

Now the CP-CD-SSM has been running online. Some graduate students of Beihang University leveraged this platform and created several innovation products. And some scientists group of NSSC-CAS got the services from this platform to demonstrate their scientific ideas before they entered into the official feasible design phase. In the future, more domain services and more complex services such as external heat flux analysis will be added to the platform. The waiting list strategy of analysis service will be optimized for simultaneous access by a mount of users.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was partly supported by the Information Program of Chinese Academy of Sciences (XXH12503-05-08).

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