8th International Systems & Concurrent Engineering for Space Applications Conference - SECESA 2018

TIC - Glasgow, 26-28 September 2018

Abstract Book

Contents

1. Committees

1.1 Technical Committee

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Valter Basso	(TAS – I)
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Annalisa Riccardi	(Strathclyde – UK)
Oliver Romberg	(DLR - D)
Andrea Santovincenzo	(ESA/SCI-FMA)
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Philippe Tanguy	(TAS - F)
Frédéric Teston	(ESA/TEC-S)
Ferdinando Tonicello	(ESA/TEC-E)
Giancarlo Varacalli	(ASI – I)
Massimiliano Vasile	(Strathclyde – UK)
Jianhua Zheng	(NSSC/CAS - CN)

1.2 Organising Committee

Massimo Bandecchi	(ESA/TEC-SYE)
Edmondo Minisci	(Strathclyde – UK)
Annalisa Riccardi	(Strathclyde – UK)
Ilaria Roma	(ESA/TEC-SYE)
Massimiliano Vasile	(Strathclyde – UK)

2. Sponsors

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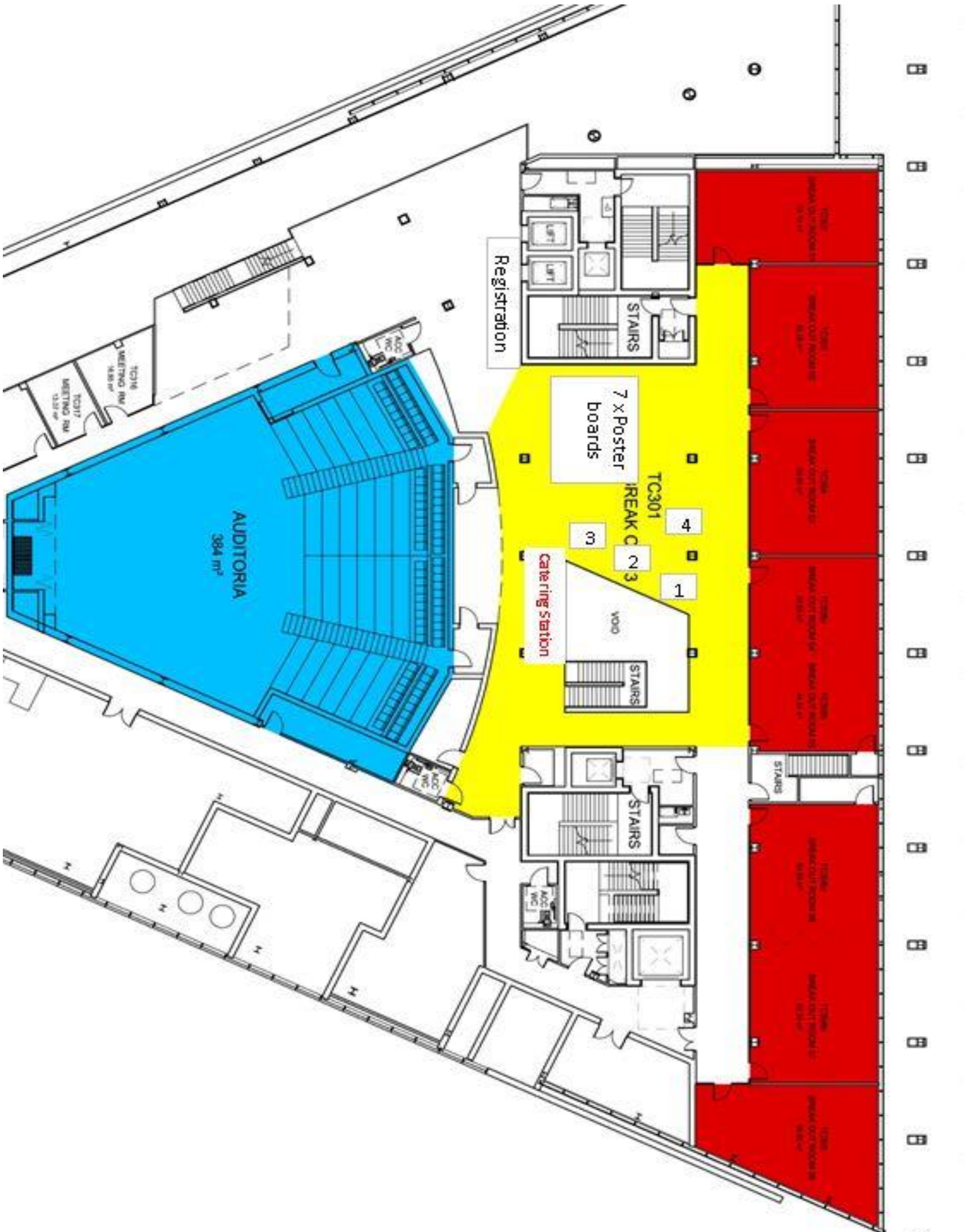
3. Conference Venue Floorplan



4. Networking Event Prior to SECESA

25 September 2018

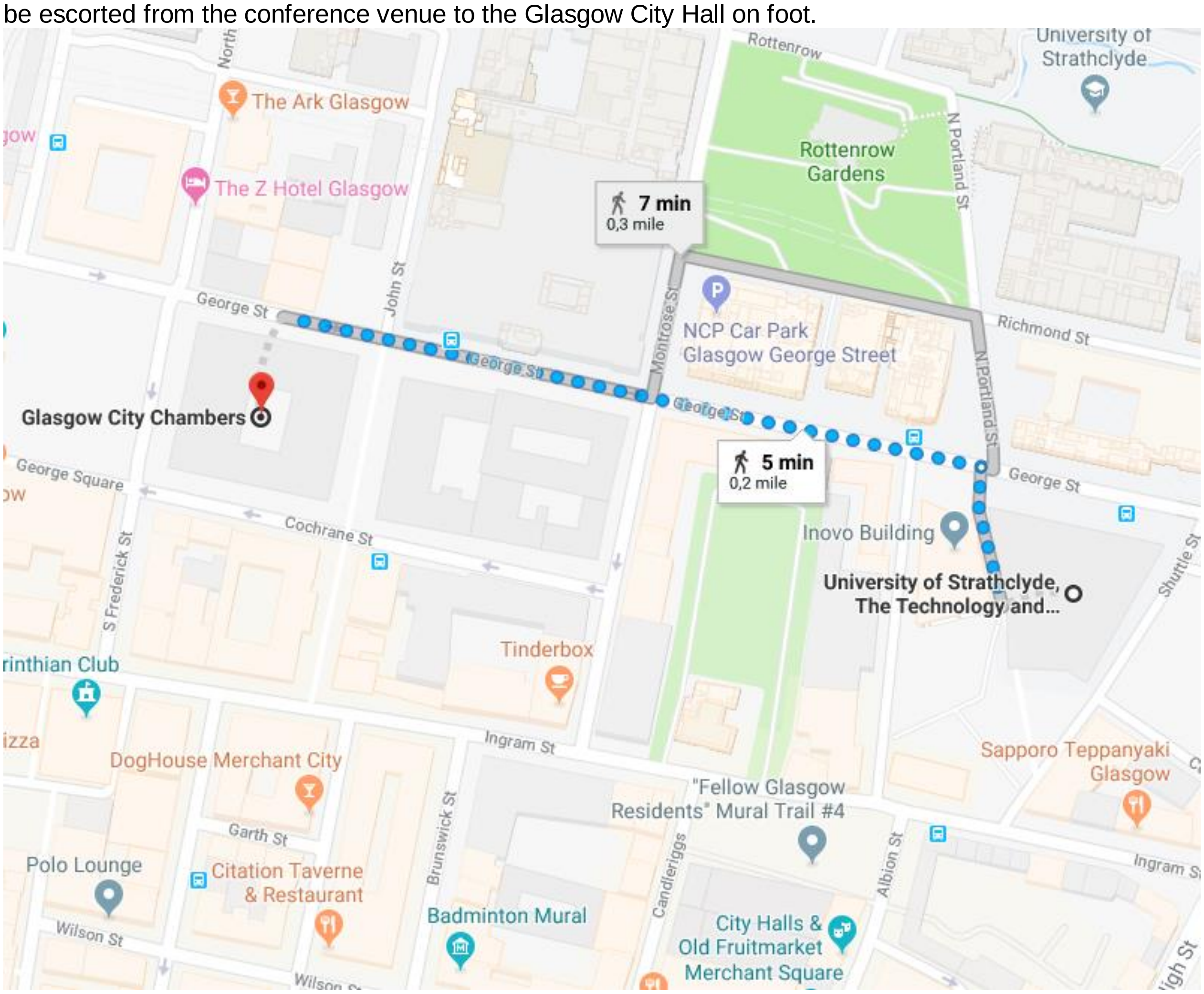
The University is hosting a FREE global networking event, accommodated by the University of Strathclyde Ocean Air and Space Strategic Theme, and Aerospace Centre of Excellence. This will be an opportunity to meet and converse with partners and peers from around the world who will be in Glasgow to attend the SECESA 2018 – the 8TH International Systems & Concurrent Engineering for Space Applications Conference. There will be an exhibition featuring a variety of cutting edge research from Strathclyde, as well as food and drinks.

The event will be held in TIC ground floor, between 3 and 5pm on the 25th of September, 2018. To register your attendance, please use this link: https://onlineshop.strath.ac.uk/conferences-and-events/engineering-faculty/mechanical-and-aerospace-engineering/oas-networking-event

5. Welcome Drink Reception offered by Glasgow City Hall

26 September 2018

The Glasgow City Council is offering a welcome drink reception open to all registered SECESA participants on the 26th of September 2018 at 7:00 pm. The location and directions are below. SECESA participants will be escorted from the conference venue to the Glasgow City Hall on foot.



6. Conference Dinner Venue

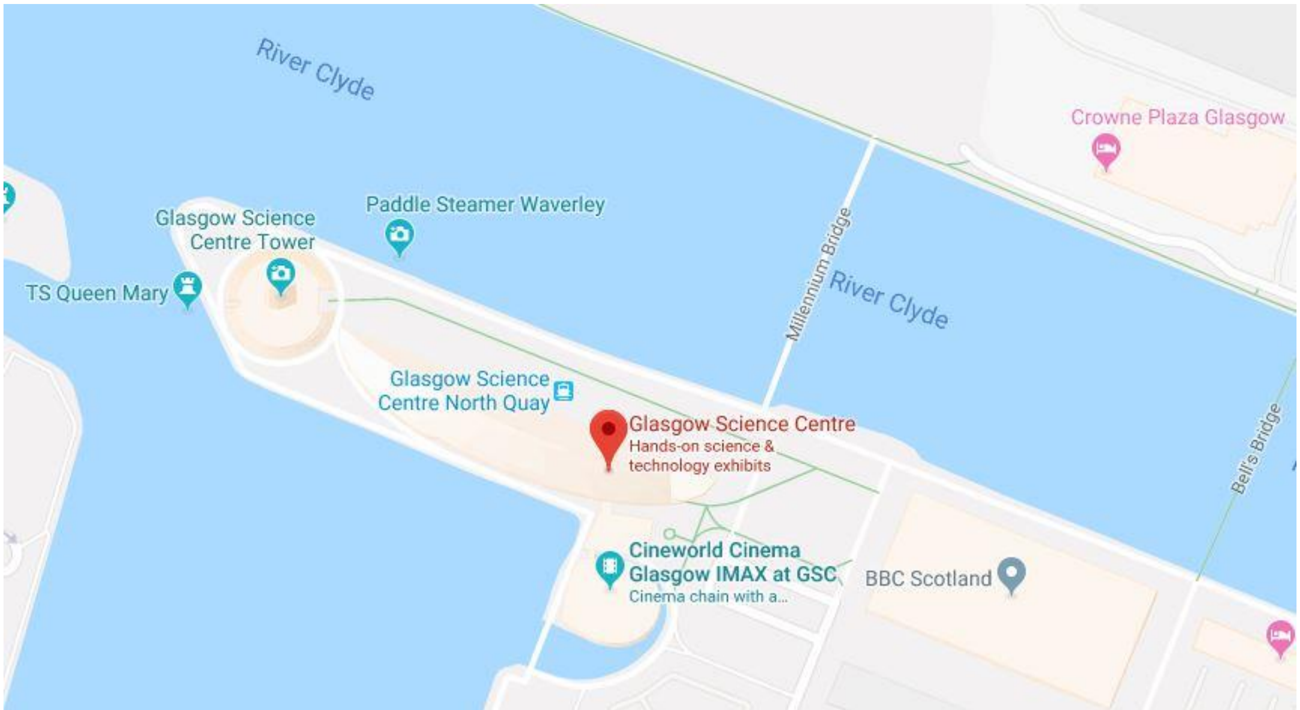
27 September 2018

The Aperitif sponsored by RHEA Group, Belgium and the Conference Dinner will take place at the Glasgow Science Centre on the evening of Thursday the 27th of September 2018. The dinner will consist in a served 3-course dinner. Before the dinner, there will be a Planetarium Show and an aperitif.

For further information concerning the dinner venue, please visit the official website of the Glasgow Science Centre:

www.glasgowsciencecentre.org

Contact:
Glasgow Science Centre
50 Pacific Quay
Glasgow
G51 1EA



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7. Final Programme

		DAY 1				
Time		***Title***	***Author***		***Company***	***Country***
		Session 1 - Digital Transformation in Space **Chair: Yolande Martinet (Airbus Defence & Space, France)**				
09:00		Introduction and Welcome Speech	Massimo	Bandecchi	ESA	The Netherlands
09:10		Introduction and Welcome Speech	Massimiliano	Vasile	University Of Strathclyde	United Kingdom
09:20		Introduction and Welcome Speech	Andrew	Heyes	University Of Strathclyde	United Kingdom
09:30		Impacts of the digital transformation on 0 / A / B1 phases, current status and perspectives	Gérald	Garcia	Thales Alenia Space France	France
09:50		Enabling concurrent engineering for complex system with innovative data ecosystem from feasibility to development and exploitation phases	Alain	Huet	ArianeGroup	France
10:10		Toward a Digital Platform for Spacecraft Manufacturing	Philipp Matthias	Schäfer	DLR German Aerospace Center	Germany
10:30		MARVL - Model Based Requirements Verification Lifecycle	Sam	Gerené	RHEA Group	The Netherlands
10:50	11:05	Networking Break				
11:05	11:35	**KeyNote Speech "Reclaiming Your Inner Geek: Systems Engineering Lessons from Safety Culture and Computer Science"**	Steven	Jenkins	Jet Propulsion Laboratory	United States
11:35		Revisit of requirement management in a model centric process for phases 0 / A / B1.	Gérald	Garcia	Thales Alenia Space France	France
11:55		IDM Applications: a new paradigm to design parametric models in a collaborative environment	Jean-luc	Le Gal	CNES	France
12:15		A Tale of Two Models: Using Concurrent Engineering and MBSE to Develop AeroCube 10	Rob	Stevens	The Aerospace Corporation	United States

12:35	13:35	LUNCH				
13:35	*withdrawn*	On the Verge of Space 4.0: Why Don't Empower Design Artefacts with Modelling Capabilities?	Christopher	Cerqueira	ITA	Brazil
13:35		Integrated Mission Design using satsearch	Sam	Gerené	spacejunkies V.O.F. (satsearch)	The Netherlands
13:55		A survey of Augmented Reality use in the Concurrent Design Facility	Robin	Biesbroek	European Space Agency	The Netherlands
14:15		Multi-disciplinary Collaborative Simulation System for Launch Vehicle Design	Jinghua	Liu	Nanjing University of Aeronautics and Astronautics	China
	Session 2 - Poster Session Elevator Pitches **Chair: Adina Cotuna (ESA, The Netherlands)**					
14:35						
15:00	15:15	Networking Break				
15:15	15:25	Introduction and Instructions for Session 3 and World Cafè Rounds	Organisers			
	Session 3 - Digital Engineering & MBSE: Applications and Plans **Chair: Gérald Garcia (Thales Alenia Space, France)**					
15:25		Implementation Strategy of Model-Based Systems Engineering at JAXA	Matsuaki	Kato	Japan Aerospace Exploration Agency	Japan
15:35		MBSE Best Practices for ESA Projects	Hans-Peter	de Koning	European Space Agency, European Space Research & Technology Centre	The Netherlands
15:45		Data-driven Systems Engineering: Turning MBSE into Industrial Reality	Louise	Lindblad	Valispace Ug	Germany
15:55		JAXA's MBSE Methodology and It's Application to an Astronomical Observation Mission	Nasa	Yoshioka	Japan Aerospace Exploration Agency	Japan

16:05	MBSE for MSR - Introducing MBSE to early phase mission design for Mars Sample Return	Jakob	Huesing	European Space Agency, European Space Research & Technology Centre	The Netherlands

World Cafè - Digital Engineering & MBSE: Applications and Plans

16:15 **Round 1**

16:45 **Round 2**

Moderators

Ralf Hartmann	Airbus
Laetitia Saoud	Thales Alenia Space

Secretaries

Ilaria Roma	ESA
Borja Garcia Gutierrez	ESA

Time Keepers

Jan Knippschild	ESA
Xavier Collaud	ESA

Panel 1 (Auditorium)

Alain Huet	ArianeGroup
Harald Eisenmann	Airbus
Ingo Gerth	OHB
Jakob Huesing	ESA
Jean-Luc Le Gal	CNES
Nasa Yoshioka	JAXA
Sam Gerené	RHEA

Panel 2 (Room 4+5)

Andrea Tosetto	Blue Engineering
Gerald Garcia	Thales Alenia Space
Hans-Peter de Koning	ESA
Jan-Christian Meyer	UNSW Canberra
Louise Lindblad	ValiSpace

Matsuaki Kato	JAXA
Norbert Brauer	Airbus

17:15 **World Cafè Resume by Moderators**

17:45 **Day 1 Conclusions**

19:00 ***Glasgow City Hall - Speech from Local Authorities & Welcome Reception***

DAY 2

Session 4 - Interactive DEMOs Session Elevator Pitches

Chair: Jakob Huesing (ESA, The Netherlands)

09:00

1	CDP4 – An industrial Open Source ECSS-E-TM-10-25A Implementation	Sam	Gerené	RHEA Group	Belgium
2	Next Generation Space Components Database for Real Time Concurrent Design	Zack	Bodinger	Space-point	United States
3	Model Hub – MBSE Sharing platform	Alex	Vorobiev	RHEA Group	Belgium
4	Collaborative System Manager (COSM 1.2) features and usage in railways and automotive sectors.	Andrea	Tosetto	Blue Engineering	Italy
withdrawn	Innovative Tool for fast Low-Thrust-Gravity-Assist Analysis in Concurrent Design Studies	Volker	Maiwald	German Aerospace Center (DLR), Institute of Space Systems	Germany
withdrawn	AOCS Simulation During the Pre-Phase A of Space Mission Studies	Ronan	Chagas	National Institute for Space Research	Brazil
5	The Strathclyde Space Systems Database: A New Life Cycle Sustainability Assessment Tool for the Design of Next Generation Green Space Systems	Andrew	Wilson	University Of Strathclyde	United Kingdom
6	Concurrent design practices for enhanced security of space systems	Matteo	Merialdo	Rhea Group	Belgium
7	Artificial Intelligence for Early Design of Space Missions in support of Concurrent Engineering sessions	Francesco	Murdaca	University of Strathclyde	United Kingdom
8	CDP4 Additional Software Development: Matlab Application For Database Interactions	Nikita	Veliev	Skolkovo Institute Of Science And Technique	Russian Federation
withdrawn	An Approach of Digitalization Regarding the Exchange of Supplier Information in Concurrent Engineering Tools	Diana	Peters	German Aerospace Center (DLR)	Germany
9	A prototype tool for the robust design optimisation of space missions	Mariapia	Marchi	Esteco Spa	Italy
10	"Nexus: a design optimisation and process integration solution"	Luca	Lanzi	iChrome	Italy

Time		Title	Author		Company	Country
	Session 5 - Systems & Concurrent Engineering Methodology Evolution & Trends Chair: Takashi Ohtani (JAXA, Japan)					
09:30		How do you go from a mission concept idea to a NASA selected mission? Formulating the Psyche Discovery Mission with JPL's Concurrent Engineering Teams	Kelley	Case	Jet Propulsion Laboratory	United States
09:50		A Through-life, Integrated and Concurrent Engineering Methodology for the Responsive Development of Large and Complex Space Systems	Luciano	Pollice	Sapienza University Of Rome	Italy
10:10	***withdrawn***	Supporting concurrent engineering by integrating with an automatic concept generation methodology	Jonathan	Menu	Siemens Industry Software NV	Belgium
10:10		Knowledge-Based Information Extraction from Datasheets of Space Parts	Francesco	Murdaca	University of Strathclyde	United Kingdom
10:30		Networking Break				
	Session 5 - Systems & Concurrent Engineering Methodology Evolution & Trends Chair: Kelley Case (NASA - Jet Propulsion Laboratory, United States)					
11:05		Responsiveness: New value creation approach for earth observation mission and the introduction of a Japanese program as an implementation example	Seiko	Shirasaka	Japan Science And Technology Agency	Japan
11:25		Rapid, Comprehensive, Mission Architecting at the Jet Propulsion Laboratory	Alfred	Nash	Jet Propulsion Laboratory, California Institute Of Technoogy	United States
11:45		The challenges of designing space systems in the context of System-of-Systems Application	Benoit	Pigneur	University College London	United Kingdom
12:05		Multistakeholder Negotiation space exploration: A Concurrent design methodology to effectively guiding group decision making to balanced preliminary design solution	Loris	Franchi	Politecnico Di Torino	Italy
12:25	13:45	LUNCH				

	Session 5 - Systems & Concurrent Engineering Methodology Evolution & Trends **Chair: Massimo Bandecchi (ESA, The Netherlands)**					
13:25	*withdrawn*	Development of The Aerospace Corporation's Human Spaceflight Team within the Concept Design Center	Kristine	Ferrone	The Aerospace Corporation	United States
13:45		Towards a Conceptual Data Model for Fault Detection, Isolation and Recovery in Virtual Satellite	Sascha	Müller	German Aerospace Center	Germany
14:05		D-CDF: Adapting ESA's Concurrent Design Facility for use in the Defence Sector	James	White	The Defence Innovation Greenhouse	The Netherlands
14:25		Launching Concurrent Design into the superyacht world	Michel	Wit	Feadship	The Netherlands
14:55		**KeyNote Speech "History of SE and Motivation to MBSE in JAXA"**	Matsuaki	Kato	JAXA	Japan
15:25	15:40	Networking Break				
15:40		Low cost space mission trends and approaches in early design phases.	Giorgio	Cifani	ESA	The Netherlands
16:00		Costing at the Speed of Light: How Your Concurrent Engineering Design Team Can Bootstrap Your Organizations Programmatic Capabilities	Jairus	Hihn	Jet Propulsion Laboratory/California Institute of Technology	United States
16:20	**INTERACTIVE DEMOs / POSTER Session / Tools Exhibition (parallel)**					
		INTERACTIVE DEMOS (Room 4)				
16:20		CDP4 – An industrial Open Source ECSS-E-TM-10-25A Implementation	Sam	Gerené	RHEA Group	Belgium
16:40		Next Generation Space Components Database for Real Time Concurrent Design	Zack	Bodinger	Space-point	United States
17:00		The Strathclyde Space Systems Database: A New Life Cycle Sustainability Assessment Tool for the Design of Next Generation Green Space Systems	Andrew	Wilson	University Of Strathclyde	United Kingdom
17:20		Model Hub – MBSE Sharing platform	Alex	Vorobiev	RHEA Group	Belgium
		INTERACTIVE DEMOS (Room 4)				
16:20		Artificial Intelligence for Early Design of Space Missions in support of Concurrent Engineering sessions	Francesco	Murdaca	University of Strathclyde	United Kingdom

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17:00	CDP4 Additional Software Development: Matlab Application For Database Interactions	Nikita	Veliev	Skolkovo Institute Of Science And Technique	Russian Federation
17:20	Collaborative System Manager (COSM 1.2) features and usage in railways and automotive sectors.	Andrea	Tosetto	Blue Engineering	Italy

INTERACTIVE DEMOS (CDF Room)

16:20	Concurrent design practices for enhanced security of space systems	Matteo	Merialdo	Rhea Group	Belgium
17:05	"Nexus: a design optimisation and process integration solution"	Luca	Lanzi	iChrome	Italy

1620-18:00 **POSTER SESSION / TOOLS EXHIBITION (Foyer)**

18:00 **Transfer to Aperitif and Gala Dinner**

The Aperitif is offered by RHEA Group Belgium

SECESA 2018

DAY 3						
Time		*Title*	*Author*		*Company*	*Country*
	Session 6 - Concurrent Engineering - Academic perspectives Chair: Javier Cubas (Universidad Politécnica De Madrid, Spain)					
09:00		CDF as a tool for space engineering master's student collaboration and concurrent design learning	Juan	Bermejo	Instituto Ignacio Da Riva (IDR/UPM)	Spain
09:20		The Spanish contribution to the 1st ESA Concurrent Engineering Challenge: design of the Moon Explorer and Observer of Water-ice (MEOW) mission	Javier	Cubas	Universidad Politécnica De Madrid	Spain
09:40		Overview and Results of the Inaugural ESA Concurrent Engineering Workshop Dedicated to CubeSats and the Subsequent Applications and Implementation for a University CubeSat Design Project	Lucas	Brewster	Carleton University	Canada
10:00		ESA Academy 's Concurrent Engineering Workshops	Johan	Venneken s	Telespazio Vega UK on behalf of ESA	The Netherlands
10:20		Introducing the Australian National Concurrent Design Facility – UNSW Canberra's end-to-end mission design tool	Jan-Christian	Meyer	UNSW Canberra	Australia
10:40	10:55	Networking Break				

	Session 7 - Concurrent Engineering - Status & Plans Chair: Carlos Corral van Damme (ESA, The Netherlands)					
10:55		Review on Concurrent Design practice in the space sector	Dominik	Knoll	Skoltech	Russian Federation
11:15		You work with me the way you talk to me – Team dynamics and team building exercise	Adina	Cotuna	ESA-ESTEC	The Netherlands
11:35		The devil is in the details: lessons learned from operations for Phase 0 studies	Xavier	Collaud	European Space Agency	The Netherlands
11:55		Considerations and first steps towards the implementation of Concurrent Engineering in later project phases	Antonio	Martelo Gómez	German Aerospace Center (DLR)	Germany

12:25	13:25	LUNCH				
13:25	13:55	**KeyNote Speech "From Design by Analysis to Design by Robust Optimisation and Beyond"**	Massimiliano	Vasile	University of Strathclyde	United Kingdom

Session 8 – Future Trends in Engineering Design

Chair: Annalisa Riccardi (University of Strathclyde, United Kingdom)

13:55		Improved Collaborative Optimization for Multidisciplinary Design Optimization Problems	Edmondo	Minisci	University of Strathclyde	United Kingdom
14:15	***withdrawn***	Multidisciplinary Design Optimization of Lander Spacecraft on Small Asteroids	Agne	Paskeviciute	Kth Royal Institute Of Technology	Sweden
14:15		A Microservice-Based Multi-Cluster Computation Platform for Space Mission Design	Huang	Xinxing	Beihang University	China
14:35		Robust Design Optimisation of Dynamical Space Systems	Gianluca	Filippi	University Of Strathclyde	United Kingdom
14:55		Phased mission system reliability with imprecise mission timing	Daniel	Krpelik	Durham University	United Kingdom
15:15		Sensitivity Analysis Tool for Complex Space Missions Using Machine Learning	Yuzhu	Zhang	National Space Science Center, Chinese Academy Of Sciences	China
14:00	15:00	Round Table - Teaching Concurrent Engineering at Universities				
14:00	15:00	MEET THE EXPERTS!				

Time		*Title*	*Author*		*Company*	*Country*
Round Table Conclusions						
Chair: Diego Escorial (ESA, The Netherlands)						
15:35		Round Table - Teaching Concurrent Engineering at Universities				

Conference Conclusions

15:45		Wrap-Up & Conference Conclusions
16:15		End of SECESA 2018

Poster Session

1	System design synthesis and multi-disciplinary optimization of a conceptual re-entry vehicle using an integrated design process	Sweety	Pate	Private Research	Belgium
2	Integrated Design and Simulation Environment for a Space Qualified Onboard Computer	Cristóbal	Nieto Peroy	Luleå University of Technology	Sweden
3	Efficient Experimental Strategies for Complex Space Simulation System	Peng	Shi	National Space Science Center, Chinese Academy of Sciences	China
withdrawn	A Microservice-Based Multi-Cluster Computation Platform for Space Mission Design	You	Song	Beihang University	China
4	Development and Validation of a CFD Optimized Integrated Pitot Sensor - Produced by Selective Laser Melting and Abrasive Flow Machining	Julian	Ferchow	Inspire Ag / ETH Zürich	Switzerland
5	Extensive Cost Estimating methodologies for the CDF GaiaNIR study	Elisabetta	Lamboglia	ESA	The Netherlands
6	ESA Academy CubeSats Concurrent Engineering Workshop	Johan	Venneken s	Telespazio Vega UK on behalf of ESA	The Netherlands
withdrawn	Current Trends in Cargo Planning and Logistics of the International Space Station	Michael	Mein	BARRIOS TECHNOLOGY LTD	United States
7	New opportunities: exploiting Concurrent Design tools in the Model Based Systems Engineering Approach	Anton	Ivanov	Skolkovo Institute Of Science And Technology	Russian Federation
8	Leveraging Mbse for Esa Ground Segment Engineering: Starting with the Euclid Mission	Marcus	Wallum	European Space Agency, European Space Operations Center	Germany

Abstracts

DAY 1

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 1 - Digital Transformation in Space

09:30 Impact of digital transformation on phases 0/A/B1 engineering activities
G. Garcia, T. Janau, R. Krawczyk
Thales Alenia Space France, Cannes, France

09:50 Enabling concurrent engineering for complex system with innovative data ecosystem from feasibility to development and exploitation phases
M. De Bank, A. Huet, A. Diveu
ArianeGroup, Les Mureaux, France

10:10 Toward a Digital Platform for Spacecraft Manufacturing
P.M. Schäfer[1*], *P.M.Fischer[2], N. Brehm[3], C. Erfurth[3], A. Gerndt[2], K. Opasjumruskit[1], D. Peters[1]*
[1] DLR Institute of Data Science, Jena, Germany, [2] DLR Simulation and Software Technology, Braunschweig, Germany, [3] EAH Jena, Jena, Germany

10:30 MARVL - Model Based Requirements Verification Lifecycle
S. Gerené[1*], *M. Bieze[1], A. Vorobiev[1], N. Phou[2], J. Fuchs[3], R. Birn[4], A. Müller[5],*
[1]RHEA Group, Leiden, The Netherlands, [2]RHEA Group, Montreal, Canada, [3]ESA, Noordwijk, The Netherlands, [4]Airbus, Friedrichshafen, Germany, [5]ScopeSET, Fischbachau, Germany

Impact of digital transformation on phases 0/A/B1 engineering activities

G. Garcia, T. Janau, R. Krawczyk

Thales Alenia Space France, Cannes, France

Abstract

Digital transformation is the today ultimate buzzword in companies. Behind all this buzz, there are deep and major on-going transformations both on the products and services we deliver to customers and on the way we work. Even if from our point of view digital transformation is more a matter of mind changing than pure technology, it is always followed immediately by a bunch of technology buzzwords like big data, artificial intelligence, digital continuity, data lake, … that evoke the set of technology coming from outside the space domain and which are building blocks of this transformation.

It is somehow difficult to understand clearly was are the concrete impacts of such a transformation on the way of working for teams involved in the early system phases of space projects (phases 0 / A / B1). This is mainly explained because, usually, all the examples of such transformation impacts are not applicable directly to the system activities of the early phases.

This paper exposes a set of concrete use cases and current implementation of major changes in the early space project phases.

This paper proposes to cover the following topics in particular :

1. Impact of the digital transformation on the day to day work (digitalisation of the processes, new way of collaborate into the team, …).
    - Use of artificial intelligence to improve the early design phase, for example the use of rule-based systems to quickly size the mission or the use of machine learning algorithms to deduce relations between parameters of a subsystem or an equipment (to perform estimations or consistency checks). This is linked to the capability to store large sets of structured information accessible to both humans and machines (for example an equipment database storing in a semi-formal way equipment properties).
    - Use of artificial intelligence algorithms to optimise systems enable to shift from a “point based engineering” where only a couple of solutions are figured out by experts and then optimised locally to a broader evaluation of solution candidates. This makes it possible to find “non-intuitive” solutions by a larger exploration of the design space helped by the increase of computing power and easiness to deploy applications on server farms.
    - Big data solutions to collaborate on end-to-end simulations and simulation results exploitations. End-to-end simulations are needed to perform system level design optimisation. They rely on many heterogeneous simulators (system of systems, mission, satellite, subsystems, …) that produce all together a huge volume of data. State of the art big data solutions coming from the Internet major players are particularly useful in this context to orchestrate, understand, display and compare simulations.
    - Natural language processing applied to requirements in order to detect relations and inconsistencies into a project requirement set. Model based engineering is not mature enough (and will certainly never be) to capture all requirements in a formal (non-textual) way. Space projects rely both on formal modelled requirements (interfaces, state machines, CAD, …) but also a lot on textual requirements. Natural language processing technologies afford to process those requirements and extract structured information.
    - Use of chatbots providing the teams with a seamless access to the engineering data. Natural language interfaces (both textual and oral) have been democratised by the personal assistants provided by big Internet players like Amazon and Google. From an engineering point of view, they simplify the access to the information by the team. This information being more and more stored into very specialised tools (from IDM-like tools to Capella and others) and thus less and less accessible to the whole team, chatbots permit this access in a very natural way.

* * * * * * * *

Enabling concurrent engineering for complex system with innovative data ecosystem from feasibility to development and exploitation phases

M. De Bank, A. Huet, A. Diveu

ArianeGroup, Les Mureaux, France

Mastering engineering data is essential to further improve the efficiency and effectiveness of the engineering processes for a complex system design programme. Getting the right version of a piece of data at the right moment from the right stakeholder and having details of changes from previous version is mandatory and becomes a competitive advantage when it avoids non-robust or not-justified design, non-qualities and extra-cost and even failures.

Thus, the implementation of a strong data management process and adapted tool is required; having compatible technical solution from phase 0 to phase E pushing Concurrent Engineering usage and facilitating iteration between advanced project and development activities is also an enormous challenge. That's why ArianeGroup have deployed a co-engineering database to store, exchange, version and baseline data and have associated to this database an innovative preparation and exploitation eco-system to compute and analyze data, able to include all types of tools: from excel to heavy industrial codes via modern programming language. It provides digital continuity all along the complete lifecycle processes and within the project teams (e.g. mechanical, propulsion, electrical, software, costing, project management, and even partners…).

More specifically, within this co-engineering database, data are described for the design engineers: that is to say at their tiniest level of granularity which is the scalar, vector, matrix, n-dimensional table, but with also comment fields to justify values and their evolution. With a set of pieces of data, engineers build up what we called a dataset. They can work every day in their dataset and at given key points publish a version of their dataset.

The publication can be signed and inserted in a baseline. Baselines enable to build up sets of consistent datasets, to create a system referential for example. Meanwhile, another disciplinary team can subscribe to some pieces of data (in accordance with a given baseline if required), previously delivered to build the input section of its dataset and start its own studies.

In addition, datasets can be varianted and versioned. Versions enable to deliver datasets all along the project phases but also to perform incremental approaches by starting quick iterations from a previous project phase before accepting the change in the current project phase. While variants facilitate working on different missions at the same time for example. Particularly, it can be used when performing multidisciplinary simulations; data are saved and classified for different generated design points, ready to be analysed with value analysis or trade-off functions encapsulated in codes snippets.

Of course, data is not replicated but access and references to data within datasets or within baselines are simplified while granting different types of rights to different teams. Each discipline can create its own viewpoint without data duplication.

On top of that, thanks to a tag functionality, transversal and prioritized views can be built up easily; it facilitates the synthesis activities, reinforces value analyses and paves the way to data science, deep learning and strong use of the knowledge welcomed in the database.

The strength of this co-engineering database and associated eco-system is having all of these functionalities combined, functionalities that are at the same time innovative and compliant from the industrial complexity required to build a complex system as a launcher.

The paper depicts the pace of ArianeGroup co-engineering database and associated eco-system since 2011, displays challenges, solutions, success stories and expected development.

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Toward a Digital Platform for Spacecraft Manufacturing

P.M. Schäfer[1],P.M.Fischer[2], N. Brehm[3], C. Erfurth[3], A. Gerndt[2], K. Opasjumruskit[1], D. Peters[1]

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In a typical spacecraft mission, stakeholders of many disciplines are involved. Of those disciplines not all are technical. There are also management and business disciplines. To move interdisciplinary work forward, a lot has been done on a technical level. A good example is the development of Model Based Systems Engineering (MBSE) tools; in particular, in the context of concurrent engineering. Cooperation between technical and management or business disciplines mostly lacks tool support. For instance, engineers can currently get automatic feedback on whether a reaction wheel fits technically into the designed system, but they are on their own to figure out whether any supplier can deliver it to their specifications in time. We present an approach to address these issues in form of digital platforms. These platforms connect tools of different stakeholders within an organization and across organizational boundaries, thus establishing a data sharing network.

Establishing this data sharing network offers a lot of opportunities for improvement, not only in the management and business realm.

One class of such opportunities lies in the digitalization of data sharing steps that involve manual data entry or copying. Manual data entry is currently sometimes unavoidable, because information is shared in human-, but not machine-readable form.

Another class of opportunities lies in new uses of available data sources. That these data sources remain unused can have multiple reasons:

1. The existence of the data source might be unknown to the party that could make use of it, which can be remedied by making existing data sources easier discoverable.
   - The party holding the data might not be interested or allowed to share the data with the potential user due to business concerns or other reasons, This is, of course, not a technical problem, and therefore not discussed in the frame of the presented work.

Our approach to capitalize on these opportunities is a digital platform concept. Using appropriate infrastructure software, it makes data sources and tools easily discoverable and usable. To prove the merit of this concept, we consider and work on several use cases.

First, we look at automatically collecting basic product information from suppliers into a product database. This information can then be made available to users of MBSE tools, such as Virtual Satellite. This obviates the need to copy data from data sheets or memory.

Second, we make the database underlying a specific MBSE tool accessible via a web service. This opens up system data to exploitation by other tools. As a proof of concept, we plan to build a web application that provides reporting on MBSE projects. This enables easy access to summary information, without the need to fire up the MBSE tool.

Third, we connect the product database mentioned above to a CAD tool. This allows storing and editing shapes of the products for use in MBSE tools without manually im- and exporting files.

And finally, we look at connecting multiple platforms into a federated network. This is motivated by the fact that multiple institutions each of which wanting to maintain data sovereignty cannot share a platform. But they might still want to exchange data automatically.

* * * * * * * *

MARVL - Model Based Requirements Verification Lifecycle

S. Gerené[1], *M. Bieze[1], A. Vorobiev[1], N. Phou[2], J. Fuchs[3], R. Birn[4], A. Müller[5],*

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1. Introduction

Model-Based System Engineering (MBSE) is increasingly being adopted in industry in favour of a document-centric approach. This improves efficiency, provided more transparency in design choices and improves the communication of engineering information between the different stakeholders.

Many (MBSE) tools are being used by industry to create a wide variety of digital models, but the exchange of information between the customer and supplier is often still very much document centric. At almost every stage there is a conversion from models to documents and vice-versa rather than a model exchange. This is time consuming, costly and can lead to loss of information and loss of traceability. This has the following down-sides:

- The same information in is repeated in different documents,
- Inconsistencies of information due to lack of configuration control,
- Documents are generated from tools or databases and are isolated from these source tools or databases
- There is an inherent difficulty in navigating between the supplied documentation
- Accessibility and visibility of relevant information to all parties involved
- Tracking of evolution, changes, agreements with impact on system definition and status is difficult to achieve

2. Common Information Platform

The Model bAsed Requirements Verification Lifecycle (MARVL) project aims to address these problems by developing a methodology and supporting infrastructure to improve the processes and the related information exchange. The MARVL project is part of the Technology Research Program of ESA which is executed by an industrial consortium comprised of RHEA, ScopeSet and Airbus [1].

The Common Information Platform (CIP) is developed during the MARVL project. It is an IT solution that supports the exchange of requirements, design and verification information between the different actors, each of whom might use different tools and might be in a variety of forms such as models and analysis reports. The main challenge is to define tools that can continuously support the evolution of information throughout the project life-cycle, while still allowing specialist tools to be used during specific phases. The CIP needs to be able to accommodate and manage many forms of information as well as MBSE based information.

PLM and PDM systems are currently being used by industry. These are very powerful but treat all the managed artifacts as black-boxes without visibility on their internal contents. There is a need for a smart but light-weight information management system that overcomes this limitation and provides end-to-end data connectivity between the content of the artifacts. The vision of the consortium is that the CIP can provide the basis for this.

The CIP is able to white-box a variety of models and even create links between the contents of these models. This provides the end-users with a seamless navigation of engineering data, going from requirements to design to verification information, irrespective of the tool the data was authored in. Currently the CIP provides the capability to interpret and transform data provided in ReqIF format and Capella. Transformation and linking support for more tools and standards is envisaged such as ECSS-E-TM-10-25A, EGS-CC and more.

3. References

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Session 1 - Digital Transformation in Space (continued, part 2)

11:35 Revisit of requirement management in a model centric process for phases 0 / A / B1
G. Garcia
Thales Alenia Space France, Cannes, France

11:55 IDM Applications: a new paradigm to design parametric models in a collaborative environment
JL. Le Gal JL, *G. Chaffarod, R. Morin, Y. Grégoire*
CNES, Toulouse, France, [2]CLEVER AGE, Toulouse, France, [3]VIRTUAL IT, Toulouse, France

12:15 A Tale of Two Models: Using Concurrent Engineering and MBSE to Develop AeroCube 10
R. Stevens
The Aerospace Corporation, El Segundo, CA, USA

Revisit of requirement management in a model centric process for phases 0 / A / B1

G. Garcia

Thales Alenia Space France, Cannes, France

1. Abstract

While a lot of progress has been made in model based engineering with the introduction of models as central source of truth in early development phases in the last years, the requirement management has not evolved a lot. Requirement management is always based on a database of requirement composed of plain text statement linked together (and sometime with the design artefacts) using traceability links. These requirements being then exchanged as document between the different stakeholders of the development process.

This paper propose to revisit the requirement management activity when the system engineering process is based on model. We believe that the interaction between the engineering model are a important source of productivity and consistency improvement for the engineering activities, in particular in early project phases where we have multiple, quickly evolving system baselines. This paper will give some example of on-going deployment or experiments at Thales Alenia Space.

It will in particular address the following points :

- How to address the semantic link between the requirements and the models : as the traceability link between models and requirement is now a standard, how to go a step further and be sure that the requirement and the model are kept in sync. For example how to ensure that a sub-system mass value taken into a mass budget (produced from a central model) is always consistent with the corresponding requirement in the sub-system specification issued by the system team.
- How to avoid effort duplication between a model that describe the systems functions or modes and the corresponding requirement into a system specification ? On some project the interface requirement documents are now replaced by “applicable” models, how far this may be extended ?
- In order to produce better specification and embrace a product line approach, how to define generic specifications and how to instantiate them for a specific project using a project architecture model ?
- Finally does the latest technologies in natural language processing (used in particular for all the conversational bots) are of any help in capturing the semantics, the data and the relations (and the ambiguities) of textual specifications.

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IDM Applications: a new paradigm to design parametric models in a collaborative environment

JL. Le Gal, *G. Chaffarod, R. Morin, Y. Grégoire*

CNES, Toulouse, France

CLEVER AGE, Toulouse, France

VIRTUAL IT, Toulouse, France

IDM-CIC and IDM-View are software developed by CNES in collaboration with CLEVER AGE and VIRTUAL IT, to provide a technical reference during the concurrent engineering process required to design a satellite. Well adapted for the pre-phase A and phase A studies, the applications also provide entries for next phases.
The aim of this environment is to offer a parametric approach to build an integrated design model of the satellite: to build 3D configuration, to perform Mass Center and Inertia budgets, to establish consumed and dissipation power budgets, and to set up a technical reference to various engineering analysis.
IDM-CIC is an editor of engineering models with capabilities of geometry modeling and management of mass and power data. The application also allows management of ephemeris files to describe the trajectory and the attitude of the satellite for different scenarios of the mission. IDM View enables to represent and display the satellite's 3D model under various viewpoints and allows to generate animated scenarios to demonstrate the satellite's overview and capabilities.

The architecture of IDM-CIC is based on a shared xml file (based on the ECSS-TM-10-25 dictionary) which is generated by an Excel interface. The shared xml file acts as a database and management of roles provides flexibility to organize collaborative work. The database is structured with elements, subsystems and units. Import and export functions offer possibilities to use templates and equipment catalogues to build the models and to exchange elements with partners.

Capabilities of geometric modeling allow first tasks of accommodation studies and assessment of Mass Center and Inertia budgets. To model the equipment, the user build 3D shapes with assemblies of simple parametric templates and has the capability to create topology shapes using Boolean operators (union, difference and intersection) to design more complex shapes. IDM-CIC is coupled with SketchUp and offers a real time control and visualization of the 3D model. IDM-CIC also enables the importation of step files produced by CAD software to manage detailed models. Coordinate systems are "attached" to the equipment models and allow simple process to build accommodation of the satellite. Moreover, management of layers enables the user to create different points of view corresponding to different needs of geometric representations.
In addition, coordinate systems can be used to define kinematic joints. Combined with implementation of formula to link parameters, the articulations allow description of mechanisms which are used to describe different configuration of the satellite (launch configuration, orbit configuration, ...).

This paper will describe the main functions of the tools and will present some illustrative examples performed at the Concurrent Design Facility at CNES.

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A Tale of Two Models: Using Concurrent Engineering and MBSE to Develop AeroCube 10

R. Stevens

The Aerospace Corporation, El Segundo, CA, USA

1. Introduction

Systems engineers often use two types of models to develop space systems; analytical models and descriptive models. They use analytical models that interconnect lower level subsystem tools to analyze total system behavior and properties such as payload performance, mass budgets, and power budgets. However, systems engineers are also responsible for tracking requirements, establishing the system concept of operations (ConOps), and assigning verification and validation (V&V) activities to ensure that the system will achieve the mission objectives. To help engineers with these tasks, interconnected descriptive models come in handy. Our team used a combination of analytical concurrent engineering tools and descriptive MBSE models to develop a pair of CubeSats called AeroCube 10.

2. Analytical Concurrent Engineering Model (CEM)

In contrast to many large satellite programs, the team's early objective was to determine what satellite missions could be performed using vehicles that deploy from a standard CubeSat deployer. Using a multidisciplinary concurrent engineering approach, we performed several system concept designs and analyzed various options to select a feasible design solution that met customer objectives.

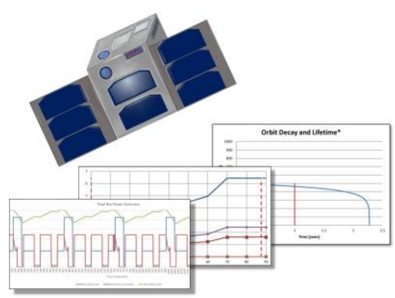

Figure 1: A CEM tool was used to evaluate CubeSat design feasibility

3. Descriptive SysML Model

In previous AeroCube projects, systems engineers had captured project artifacts in the form of static documents, such as requirements spreadsheets, interface control documents, and verification lists. For AeroCube 10, however, the team captured these important descriptions in a SysML model and interlinked them together. For example, we linked requirements with V&V activities and a physical architecture. Document artifacts were no longer central to the design process and were only exported as desired. This model based approach was developed with reusability in mind for the next AeroCube.

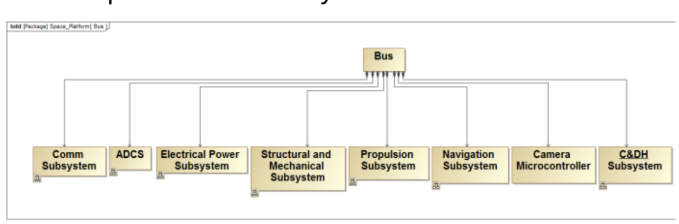

Figure 2: Requirements, physical architecture, and V&V activities were captured in a SysML model

4. Model Integration

Recognizing that the two types of models can share information, we linked them together to directly couple our concept design with our requirements, ConOps, and V&V activities. For example, a maximum mission altitude calculated using a CEM tool can be directly imported into a SysML model as a requirement, where it is then associated with vehicle ConOps and assigned verification by test activities. The processes developed here are also extensible to larger spacecraft program.

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Session 1 - Digital Transformation in Space (continued, part 3)

13:35 Integrated Mission Design using satsearch
K. Kumar[1], *A. Vaccarella[1], N.P. Nagendra[1], S. Gerene[2], L. Lindblad[3]*
[1]spacejunkies V.O.F. (satsearch), Noordwijk, The Netherlands, [2]RHEA Group, Leiden, The Netherlands, [3]Valispace UG, Bremen, Germany

13:55 A survey of Augmented Reality use in the Concurrent Design Facility
A. Cipriano, *R. Biesbroek*
European Space Agency, ESTEC, Noordwijk, The Netherlands

14:15 Multi-disciplinary Collaborative Simulation System for Launch Vehicle Design
S. Y. Li[1], *J. H. Liu[1], B. Qiao[2*]*
[1]Institute of Aerospace System Engineering Shanghai, Shanghai, China , [2]Nanjing University of Aeronautics and Astronautics, Nanjing, China

Integrated Mission Design using satsearch

K. Kumar[1], A. Vaccarella[1], N.P. Nagendra[1], S. Gerene[2], L. Lindblad[3]

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[2]RHEA Group, Leiden, The Netherlands
[3]Valispace UG, Bremen, Germany

For space systems engineers to make design choices, they have to know what products are available on the market and their specifications. The effort required to find products that satisfy mission requirements and constraints can necessitate an inordinate level of manual effort, including spending hours “Googling”, wading through long PDF datasheets, emailing and calling suppliers, and relying on a network of “space friends”.

Over the last decade, NewSpace companies have popped up all around the world. The global supply chain is becoming increasingly fragmented; hence the search problem is only worsening. Finding the right products has turned into a colossal problem, costing precious engineering man-hours. Fixing industry-wide search is vital to ensuring continued and sustainable growth of the space industry over the coming decade.

To fix the search problem, we are building satsearch: the first global marketplace for space. By consolidating, harmonizing, and structuring global supply chain data, we are making the search for space products simple. This helps to increase engineering efficiency, reduce lifecycle costs and increase transparency across the industry.

In this paper, we present a new design methodology called *Integrated Mission Design* (IMD). IMD is built around the premise that deep integration of supply chain data in the mission design process will lead to strong gains in terms of optimality and robustness. The IMD approach belongs to a broader class of *Data-Driven Design* (D^3) methods for complex systems engineering. IMD enables direct analysis of the sensitivity and robustness of the overall system to specific design choices. We review how IMD fits within the scope of Model-Based Systems Engineering (MBSE). IMD enables complex algorithms to be deployed to assist engineers in the process of rapidly testing design concepts and pinpointing feasible solutions in the design space.

We detail our efforts to develop satsearch for IMD, by generating a knowledgebase that enables direct integration of global supply chain data into the design process. Our approach rests on converting unstructured product datasheets into electronic, human-readable, machine-readable datasheets (EDS) to populate the satsearch knowledgebase. The satsearch knowledgebase has been integrated into a number of advanced design tools and platforms. We provide an overview of integrations with RHEA Group’s CDP4™ platform for concurrent design and Valispace’s browser-based platform for collaborative development of hardware projects. In both cases, we present short scenarios to elucidate how engineers can utilize the integrations for IMD.

Efforts to develop EDS are underway across the industry; our unique proposition is to leverage EDS to integrate supply chain data directly into systems engineering software. We summarize the research that we have conducted to develop a space systems ontology that underpins the generation of EDS. We also provide an overview of the architecture of our data pipeline that ingests source datasheets and generates EDS that is served to our integrations through our knowledgebase API. We discuss future developments to deploy structured supply chain data through our API integrations, enabling engineers to develop complete missions using the IMD approach.

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A survey of Augmented Reality use in the Concurrent Design Facility

A. Cipriano, *R. Biesbroek*

European Space Agency, ESTEC, Noordwijk, The Netherlands

1. Abstract

Augmented Reality (AR) is an interaction tool that overlays virtual information onto the real environment. AR already has practical applications in many engineering fields, such as the automotive and aerospace industries. Technologies such as the HoloLens, an AR Head-Mounted Display, have recently started being used by Space Agencies to perform maintenance activities at the International Space Station and during assembly, integration and verification. The purpose of the work presented in this paper is to assess if such technology could also be advantageous for the early phases of space mission design, by defining possible HoloLens' applications to be used during CDF sessions. A preliminary definition and assessment of usefulness for the CDF of four different applications is presented. For the definition of these applications, a structured survey was conducted during an AR brainstorming session at the CDF, with several CDF users. From this activity and a literature study on how other industries are integrating AR in their fields, preliminary requirements for AR use in the CDF have been defined. Based on these requirements, a prototype using a HoloLens is to be developed and tested in the CDF.

Figure 1: Example of on-board training for centralised filter replacement at the International Space Station, using a HoloLens [1].

2. References

[1] Kaj, H., Jaakko, K., Nikos, F., Paul, K., *et al*.: Augmented Reality for AIT, AIV and Operations, Tech. Report, funded by the European Space Agency under contract 4000113373/15/NL/MH, 2017.

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Multi-disciplinary Collaborative Simulation System for Launch Vehicle Design

S. Y. Li[1], *J. H. Liu*[1], *B. Qiao*[2*]

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A multi-disciplinary collaborative simulation policy for the overall design of launch vehicle is presented. The multi-disciplinary processes and their relationships for launch vehicle design are first examined to determine the function modules of the co-simulation platform, which can be depicted in Figure 1.

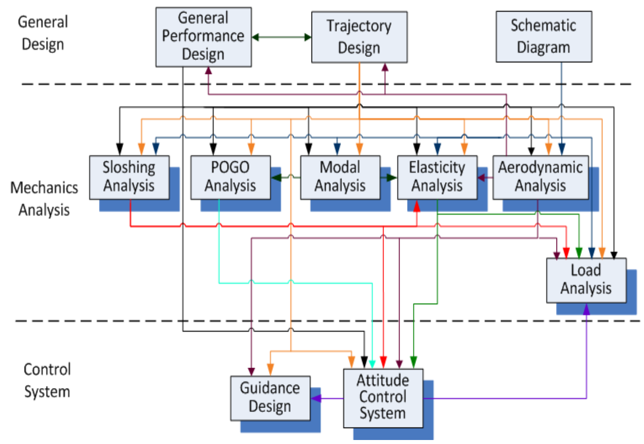

Figure 1: Multi-disciplinary processes of launch vehicle design

An architecture of multi-disciplinary collaborative simulation for launch vehicle design is established based on the supporting software framework as demonstrated in Figure 2, in which the overall design process of launch vehicle that covers the task allocation, data transfer and design simulation is formed through customised workflow to achieve the customization of task, the automation of data transfer and the modularization of computation.

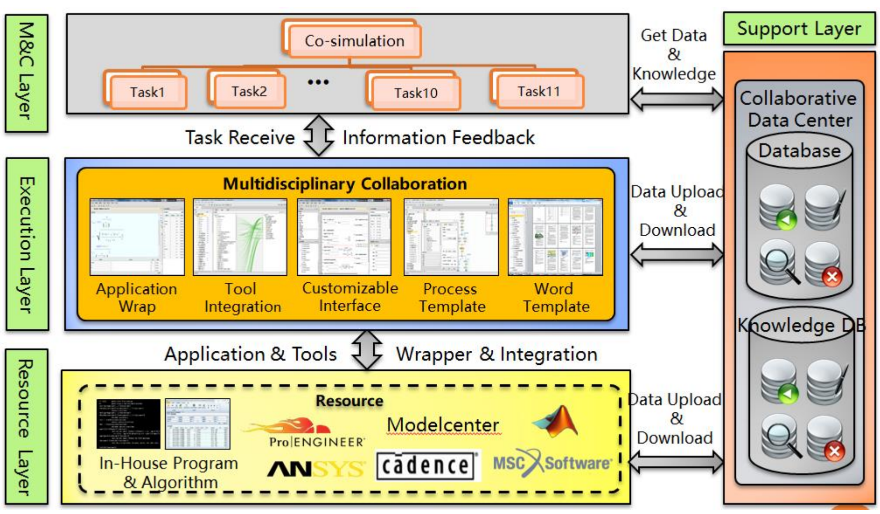

Figure 2: Co-simulation support software framework

The application scenario of the multi-disciplinary collaborative simulation system and its implementation in launch vehicle designs are presented in the paper, which indicates that the system not only obviously improves the efficiency of the overall design of the launch vehicles, but also shortens the cycle of design and guarantees the accuracy of the data exchange.

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Session 3 - Digital Engineering & MBSE: Applications and Plans

15:25 Implementation Strategy of Model-Based Systems Engineering at JAXA
M. Kato, *A. Noda and T. Iwata*
Japan Aerospace Exploration Agency, Tsukuba, Japan

15:35 MBSE Best Practices for ESA Projects
H.P. de Koning, *J. Lorenzo, H. Metselaar*
European Space Agency, ESTEC, Noordwijk, The Netherlands

15:45 Data-driven Systems Engineering: Turning MBSE into Industrial Reality
L. Lindblad, *M. Witzmann, S. Vanden Bussche*
Valispace, Bremen, Germany

15:55 JAXA's MBSE Methodology and It's Application to an Astronomical Observation Mission
N. Yoshioka, *Y. Takei, M. Kato, T. Iwata*
Japan Aerospace Exploration Agency, Tsukuba, Japan

16:05 MBSE for MSR - Introducing MBSE to early phase mission design for Mars Sample Return

J. Huesing[1]; *F. Beyer*[1], *H.-P. de Koning*[1], *J. Delfa*[2]
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Implementation Strategy of Model-Based Systems Engineering at JAXA

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1. Abstract

The main mission of the System Technology Unit (STU) of the Japan Aerospace Exploration Agency (JAXA) is to transform an idea leading to a space mission into a valuable and feasible plan. The STU's activity focuses on the mission and system design for a wide range of studies from idea creation to Phase-A of new missions including that include conceptual development, conceptual design, and system trade-off analysis [1].

In order to enhance this role, for more than two years the STU has conducted a study on Model-Based Systems Engineering (MBSE) to improve systems engineering (SE) capability, focusing on the benefits of MBSE: single source of truth, rigor systems engineering, and the reusability of system models.

The study shows that MBSE does not always lead to improved systems engineering capability and efficiency. To exploit the benefits of MBSE, we must develop MBSE methodology suitable for JAXA's systems engineering process and practices. Given the various aspects to be considered for implementing MBSE into organizations, we refer to the general framework for MBSE implementation described in [2] as follows:

- Process:
  What are the features of SE and the project management process for systems development at JAXA?
- Methods (MBSE methodology):
  How to model the SE activity of systems development at JAXA and how to apply SysML
- Tools:
  What tools are suitable for our process and method?
- Environment:
  What are the support infrastructures to conduct MBSE for systems development at JAXA?

From the standpoint of process, we will introduce a brief overview of project management reform in 2017 for space systems development, and illustrate how the reform affects SE at JAXA.

Considering the concept of project management reform and the current capability of MBSE at JAXA, the STU has devised a strategy for how to apply MBSE to space systems development at JAXA. The strategy consists of three types of MBSE methodology with different objectives. We developed one of the three methodologies covering pre-Phase A to Phase A, and have begun applying this methodology to certain missions as trials. This paper presents the objectives of those trials and shares the results thereof.

The preparation of tools and the environment for MBSE entails an ongoing process through an actual design study. The STU currently uses MagicDraw as a MBSE tool to identify the functions needed for our process and methodology. Moreover, the STU also develops a framework to exchange information with domain-specific tools such as MATLAB, STK, CAD and other specific tools brought by domain experts. This paper also presents the concept of MBSE infrastructure and future works.

2. References

[1] Yuta Nakajima, Atsushi Noda, Noriyasu Inaba, The Emergence Studio: New Collaborative Engineering Environment for JAXA's Mission Design Activities, 7th International Conference on Systems & Concurrent Engineering for Space Applications, 2016.
[2] Jeff A. Estefan, Survey of Model-Based Systems Engineering (MBSE) Methodologies, INCOSE MBSE Focus Group, 2007.

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MBSE Best Practices for ESA Projects

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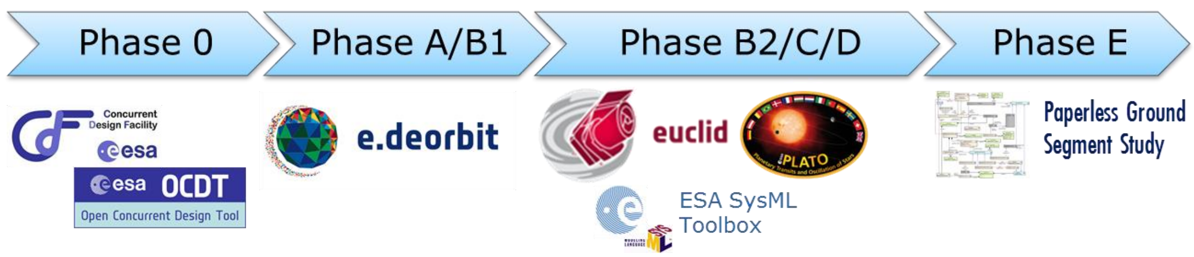
The use of Model-Based Systems Engineering (MBSE) has been steadily increasing at ESA since 2012 with full application in a number of projects – in particular Euclid and e.Deorbit – as well as in the early concept and feasibility studies in the Concurrent Design Facility (CDF). The proposed paper outlines a number of best practices and guidelines that have been derived with the early adopters and are now being implemented for (future) ESA projects.

MBSE is part of the ongoing transformation towards a full digital engineering support across all disciplines and lifecycle phases of the projects. Since this is clearly a complex improvement process involving many choices concerning methodology, standards and tools, as well as involving many different actors, ESA decided it is timely and useful to develop a 'living' best practices guide. The guide serves as a common knowledge resource shared between projects, studies and research & development work. It is not only meant for internal use at ESA, but also to be shared with the European space sector. The goals are:
To facilitate and promote efficient and effective use of MBSE on space system projects
1. To share practical knowledge on what works well and what does not
- To harmonize use of MBSE standards and methodologies, from the beginning
- To build up shareable resources: model libraries, profiles, usage patterns, repositories

An overview of examples from real projects and studies is given in the diagram below.



The focus is on standards and methodologies rather than tools, in particular:
- OMG Systems Modeling Language (SysML), current version 1 and future version 2
- ECSS-E-TM-10-23 "System engineering - Space system data repository"
- ECSS-E-TM-10-25 "System engineering - Engineering design model data exchange (CDF)"
- ESA SysML Toolbox, including a metamodel/profile, as developed for Euclid and PLATO
- ARCADIA methodology from the Thales Group
- ESA Architectural Framework (ESA-AF) for System-of-Systems (SoS) architectures

Nevertheless implementation examples with actual tools will be shown, although ESA naturally takes a neutral standpoint w.r.t. tools, avoiding endorsement of specific ones.

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Data-driven Systems Engineering: Turning MBSE into Industrial Reality

L. Lindblad, *M. Witzmann, S. Vanden Bussche*

Valispace, Bremen, Germany

1. Introduction

This paper expands upon a paper presented at the SECESA in Madrid 2016 [1], which showed that although some companies in the space industry are in the process of moving from a document-based systems engineering approach to MBSE, the existing MBSE tools are currently not widely adopted due to their complexity and inflexibility. The proposed solution was a browser-based, collaborative engineering tool which ensures consistent data throughout the whole project. This paper goes further and presents the need for a new data-driven systems engineering approach to spread the use of MBSE in the industry.

2. Data-driven Systems Engineering

One of the reasons that MBSE is not yet widely adopted by the industry is that while it provides good representation form of models, it quickly becomes too complex and inflexible for practical use. Moreover, the underlying data and calculations for verification and analysis of models is often overlooked, which leads to problems with data inconsistency and duplication. Data-driven systems engineering (DDSE) is proposed to and enable a wider spread of MBSE throughout the industry. Here, data-driven refers to an approach where engineering data and associated structure, links and connections constitute the foundation of the systems engineering process.

3. A Browser-based, Data-driven Systems Engineering Tool

As a practical example, the evolution of the previously presented browser-based, data-driven systems engineering tool, Valispace, is presented. With this tool, a common and consistent dataset of engineering parameters and formulas is maintained throughout a project. When any parameter changes, the effect immediately ripples through the system and other, dependent parameters, as well as documentation, are automatically updated. The data is structured in simple models, which brings the majority of the benefits of MBSE but with almost all complexity abstracted from the user. The dataset serves as a 'single source of truth' throughout the entire product design lifecycle, which can easily be integrated with any further specialized tools or models.

4. Conclusion

In conclusion, the proposed data-driven systems engineering approach and the implemented browser-based collaboration tool is needed to turn MBSE to industrial reality by ensuring that connected data is a central part of the engineering process.

5. References

[1] Lindblad, L., Witzmann, M., and Vanden Bussche, S.: Systems Engineering from a Web Browser: Turning MBSE into Industrial Reality, SECESA 2016.

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JAXA's MBSE Methodology and It's Application to an Astronomical Observation Mission

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1. Abstract

In response to a series of mission failures in the early 2000s, the Japan Aerospace Exploration Agency (JAXA) established the systems engineering process and project management process aiming at the reliable system development. In the 2010s, JAXA's systems engineering has reached a turning point again due to various factors such as a complication of space systems and an increase in stakeholders.

In the concept development and concept design phase, which is the most important phase of system development, it is required to appropriately capture mission requirements and other requirements to be considered. Furthermore, it is also required to comprehensively request traceability from the requests to System of Interest (SoI). The System Technology Unit (STU) at JAXA has developed a methodology applying MBSE to this phase. It is called "MBSE Methodology". The basic concept of MBSE Methodology is shown below [1].

- Concept of Systems Engineering based on "Value Creation" instead of "Product Creation."
- "Designing a Journey"—in order to comprehensively define the requirements.

Requirements derived based on the concept described above are managed in a unified model (Single-Source-of-Truth) and their traceability are ensured. These are known as the strengths of MBSE. Since the latest correct information is always saved, it enables engineers to develop satellites based on the up-to-date information.

This paper demonstrates the MBSE Methodology for general astronomical satellites information of using an astronomical observation satellite mission. It also shows how to build the MBSE Methodology as a model. The tool used is MagicDraw.

Through analysing "Designing a Journey" of a system, we were able to capture what are mission requirements and what the system should do. In addition, we confirmed that the derivation of system requirements can be carried out comprehensively and consistently from the mission requriements which was missing in the concept development and concept design phase. Through analysing "Product Creation", we confirmed that mission requirements and system requirements can be quantitatively connected. By constructing the requirements captured as described above as a model, we have managed to centrally manage the information and also succeeded in extracting the desired information from it.

Positive feedback was received on the application results from the astronomy observation project members.

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MBSE for MSR - Introducing MBSE to early phase mission design for Mars Sample Return

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The return of samples from Mars has remained the top priority of the international Mars science community for several decades. Following the signature of a letter of intent in April 2018, ESA and NASA are exploring a potential collaboration in the implementation and execution of an international Mars Sample Return (MSR) campaign. NASA's Mars 2020 mission is designed to perform the initial sample acquisition and caching on the Martian surface. A subsequent Sample Return Lander (SRL) mission would contain a Sample Fetch Rover (SFR) to collect these sample tubes and return them to the SRL, where a Mars Ascent Vehicle (MAV) would launch the contained samples into Mars orbit. The Earth Return Orbiter (ERO) would be in place in Mars orbit and responsible for locating and capturing the sample container, and ensuring its safe return to Earth. In the frame of this campaign, ESA initiated industrial phase A/B1 studies on the Earth Return Orbiter mission and the Sample Fetch Rover.

Following first applications of Model Based Systems Engineering (MBSE) in different project phases of ESA space missions, the aim is to capitalise on this experience by establishing a harmonised MBSE approach, suited for different lifecycle phases in the design and development of space missions. The current ESA activities for MSR have several study constraints and drivers, which appear to make the application of a dedicated MBSE approach particularly beneficial for several aspects: The necessarily short study duration favours a more model-centric than document based exchange of information; the overall short development schedule for the elements emphasizes the importance of a logical flow of requirements and their traceability from an early phase; complex interfaces with several actors including industrial contractors, NASA/JPL and ESA benefit from a collaborative definition and management; and traceability of the functional and operational allocations throughout the requirements and elements facilitates a common understanding and an efficient implementation.
Furthermore, the Harwell Robotics and Autonomy Facility (HRAF) activity, which aims to develop a MBSE framework to run simulations and semi-automated Validation and Verification, is being considered to model certain phases of MSR.

This paper will, after briefly introducing the MSR campaign, describe how the MBSE approach was tailored for the ESA MSR studies, how it was deployed throughout the different actors, its use during the activities, first experience on its usability and how the HRAF facility could be utilised during the mission development.

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DAY 2

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 4 – Interactive DEMOs Session Elevator Pitches

1 CDP4 – An industrial Open Source ECSS-E-TM-10-25A Implementation
S. Gerené[1], *M. Bieze[1], M. Fijneman[1], A. Vorobiev[1], N. Phou[2]*
[1]RHEA Group, Leiden, The Netherlands, [2]RHEA Group, Montreal, Canada

2 Next Generation Space Components Database for Real Time Concurrent Design
Z. Bodinger, *G. Colonna, R. Fleeter, M. Menapace, E. Stefanini*
Space-Point, Italy

3 Model Hub – MBSE Sharing platform
S. Gerené, *A. Vorobiev*
RHEA Group, Leiden, The Netherlands

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A. Tosetto
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5 The Strathclyde Space Systems Database: A New Life Cycle Sustainability Assessment Tool for the Design of Next Generation Green Space Systems
A. R. Wilson[1], *M. Vasile[1], C. Maddock[1], K. Baker[2]*
[1]University of Strathclyde, Aerospace Centre of Excellence, Glasgow, United Kingdom,[2]Glasgow Caledonian University, School of Engineering and Built Environment, Glasgow, United Kingdom

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7 Artificial Intelligence for Early Design of Space Missions in support of Concurrent Engineering sessions
F. Murdaca[1], *A. Berquand[1], A. Riccardi[1], T. Soares[2], S. Gerené[3], N. Brauer[4]*
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8 CDP4 Additional Software Development: Matlab Application For Database Interactions
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9 A prototype tool for the robust design optimisation of space missions
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10 Nexus: a Process Integration and Design Optimisation Solution
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CDP4 – An industrial Open Source ECSS-E-TM-10-25A Implementation

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1. Introduction

ECSS-E-TM-10-25A is a technical memorandum published under the E-10 System engineering branch in the ECSS series of standards, handbooks and technical memoranda. The purpose of ECSS-E-TM-10-25A is the following:

> *"This Technical Memorandum facilitates and promotes common data definitions and exchange among partner Agencies, European space industry and institutes, which are interested to collaborate on concurrent design, sharing analysis and design outputs and related reviews. This comprises a system decomposition up to equipment level and related standard lists of parameters and disciplines. Further it provides the starting point of the space system life cycle defining the parameter sets required to cover all project phases, although the present Technical Memorandum only addresses Phases 0 and A."* [1]

The topic of this paper is the status of the CDP4, the RHEA Concurrent Design Platform, which is an implementation of ECSS-E-TM-10-25A Annex A and C, that is released with an open source license and publicly available on GitHub [2] [3].

2. CDP4 Overview

The CDP4 is an implementation of the ECSS-E-TM-10-25A. For the implementation of the CDP4, Annex A has been extended with extra concepts to support the design of complex systems. These extensions are based on the RHEA experience of the CDP3, pre-cursor software to CDP4 [2]. The extensions allow users to create SysML like diagrams as well as the creation of RIDs in support of design reviews.

The CDP4 is fully inter-operable with the ESA OCDT [3], or any other implementation of ECSS-E-TM-10-25A. This means that teams can mix using these applications. Some team members may prefer to use CDP4 desktop and CDP4 Excel integration as end-user application, whereas others may prefer ConCORDE, the ESA OCDT Excel addin. Some organizations may prefer to deploy the CDP4 Web Services; others may prefer to deploy the OCDT WSP. There are differences between these applications and the features they provide. For instance, the CDP4 Server is designed to keep track of all the changes that have been made on any data (who did what, when). With the time-travel capability it is possible to get access to the complete state of all the design information at a particular point in time.

The CDP4 has three major end-user applications that can be used in tandem: a desktop application, excel integration and a web application. This allows users to choose the environment they like best to perform the modelling and engineering tasks they need to do. The CDP4 desktop application makes it easier to organize all the windows that may be required to show the data that is relevant for a particular task. It also provides many plugins such as adding Python support; Python can be used to perform analysis on a model, ranging from mass budget computations, requirements coverage as well rule checking. The CDP4 excel integration provides the tools to perform parametric analysis on CDP4 data and publish the results to the team.

3. References

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Next Generation Space Components Database for Real Time Concurrent Design

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In the eight years since we began development of an on-line database of actual space components to increase the fidelity of concurrent engineering results, the fields of web and database search have revolutionized many elements of our everyday lives while they have undergone major technological and structural transformations. We are used to shopping on line finding products starting from even a rough description or an image, sometimes using words that are not actually present in the product description or that we have spelled partially or erroneously. Particularly in the cubesat and microspace areas, the rate of new product introduction is unprecedented in the history of space systems, requiring much more rapid and on-the-fly updating of database contents.

Beginning in 2017 Space-Point has undertaken a major redesign of our search engine, database structure and system functionality to enable more flexible searches and more frequent updating of the content including addition of new single product entries without awaiting periodic database upgrades. We have also upgraded the user and API interfaces.

Specific improvements include:
- Modernized web interface
- Streamlined data entry
- Migration of entire existing database to new framework
  (simultaneously checking and updating content and links)
- Verify availability of Application Programming interface (API) (web services) to all client CDFs

To accommodate the large number of academic and smaller organization users who do not have access to concurrent facilities, we have reintroduced an upgraded manual access porthole to the database at a cost compatible with these organizations' budgets and typically lower usage and performance requirements.

The paper describes some of the details of the new architecture and gives examples of how the upgraded design functions from the user interface perspective.

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Model Hub – MBSE Sharing platform

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1. Introduction

In the current information age, an unprecedented wealth of data can be found on the public internet. Search engines like Google, or online encyclopaedias, such as Wikipedia, provide a means to find and share knowledge and disseminate information. Services like GitHub and BitBucket provide a means to share source code of software projects with a clear goal of supporting open source communities by providing their services free of charge.

Even with the availability of these services it is difficult to find specific kinds of information, especially quality (MBSE) Models. When performing an online search, using for example Google, for digital models, such as UML, SysML, Capella, ECSS-E-TM-10-25A, ReqIF, Ecore, etc., the results are very disappointing. Models are all over the place, very simplistic, and many times undocumented.

2. The Model Hub

The fact that quality models are difficult to find also makes it difficult for newcomers to learn or experienced people to share their knowledge. The Model Hub, an online platform to freely share digital models, aims to overcome these issues. The intention is to create a dedicated place and an online community to share digital models and exchange experiences and ideas. The Model Hub, or MoHu, provides users a means to create accounts, teams and projects. Within a project, a person or a team can upload and download models, provide a description of said models, and engage in an active discussion. Both private and public projects are supported, teams can choose to make their project publicly available or not. The IPR of the models will remain with the authors, with MoHu providing means to associate a license to a model so it is clear to the community under what conditions the models may be distributed and used.

Even though an existing service such as GitHub could be used, this platform is purpose built for sharing source code of software products. In order to promote digital engineering and MBSE a dedicated platform such as the Model Hub can be a great asset to the engineering community. Engineers, students, and organizations can use this platform as a means to promote their capability and share their experience

The current state of the Model Hub is focused on sharing and communicating about the content of the models. In the near future, the Model Hub will be extended to also automatically assess the quality of models, execute rules and analysis based on these models. The Model Hub can be found at https://modelhub.org

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Collaborative System Manager (COSM 1.2) features and usage in railways and automotive sectors.

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1. Introduction

Collaborative System Manager was originally developed by BLUE Engineering with the collaboration of ThalesAleniaSpace Turin. Since 2015 BLUE Engineering starts using COSM in its core business projects, in railway and automotive sectors. Several specific model and algorithms are implemented and used from early to detailed design phases.

1.1. Improvements

Version 1.2 of COSM includes a set of railways relevant algorithms, Electrical Vehicle automotive algorithms.

The Main Library (main COSM executable) includes a new View, like a bill of material for a specific option, and a new 3D viewer, able to load also CAD data.

Figure 1: CAD import Example.

1.2. Usages

COSM is used in feasibility phase of both Automotive and Railways Sectors mas budgets and performances are evaluated and help to define specifications for trainset/automotive design.

The tool is used till the final design phase to perform mass balance validation based on final layout and suppliers equipment data.

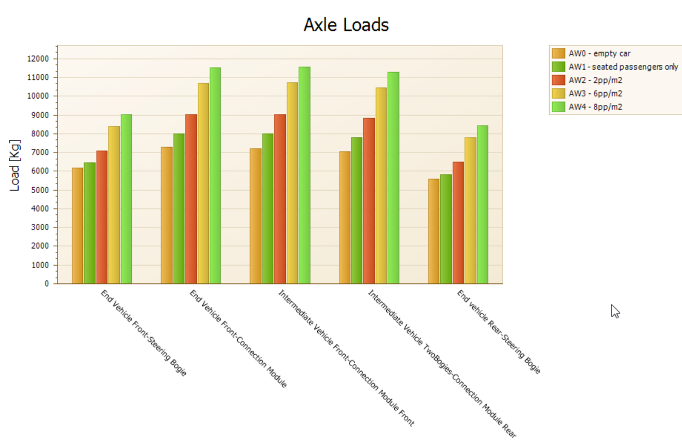

Figure 1: Trainset Axle Load Calculation Example.

The Strathclyde Space Systems Database: A New Life Cycle Sustainability Assessment Tool for the Design of Next Generation Green Space Systems

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1. Introduction

The use of Life Cycle Assessment (LCA) is currently being pursued by the European Space Agency (ESA) to allow decision-makers within the space industry to minimise environmental impacts and define new optimality criteria for space systems [1]. However, with Life Cycle Sustainability Assessment (LCSA) being predicted as the future of LCA [2], moving towards space-based LCSA is a logical next step for the space industry. This paper will present the methodology used in an open-source LCSA platform called the Strathclyde Space Systems Database (SSSD) under development at the University of Strathclyde for the design of space missions, outlining the integration of social and economic aspects with environmental LCA.

2. Materials and methods

The SSSD has been built to conform to international ISO Standards 14040/14044 as well as the ESA Space system LCA guidelines. For LCA, a tier-style approach was adopted in order to come to a detailed assessment ranging from mission level to individual activity level for the space, ground and launch segments across each phase of a space mission. A range of midpoint indicators from a variety of sources were used for the impact assessment categories to give a full spectrum of relevant environment results relating to a typical space mission. Social processes were built based on the Sustainable Development Goals and the United Nations Environment Programme and Society of Environmental Toxicology and Chemistry guidelines on Social LCA (SLCA) across 5 different stakeholder categories. These stakeholder categories are based on an evaluation scheme used by an intervention and associated severity risk score to allow a social score for each Stakeholder Category to be reached. The Life Cycle Costing (LCC) aspects were built into the environmental processes by splitting monetary flows into costs and revenues across a variety of cost categories for the space, launch and ground segment. As each category within SLCA and LCC use common units (score and money), each assessment has the ability to come to a single score and be included as impact categories within LCA.

3. Results and discussion

An example of life cycle sustainability results achieved using the SSSD will be presented for a variety of space systems/components using the SSSD. These results will then be tested for the viable integration within the concurrent design process and with other design tools at the University of Strathclyde to assist with the ecodesign of space missions. This will be conducted at the Concurrent and Collaborative Design Studio at the University of Strathclyde.

4. Conclusion

It is hoped that the SSSD will be released publically by mid-to-late 2019 where it will contribute to the global sustainability agenda by allowing the space industry to become more accountable and responsible for their operations. The tool will therefore assist decision-makers in choosing sustainable technologies and products that are not only cost-efficient, eco-efficient and socially responsible, but also ones that can easily justify and evidence their sustainability.

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Concurrent design practices for enhanced security of space systems

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1. Introduction

Hardly a day goes by when there isn't a new article published about the growing concern of cyber-attacks on critical systems. Recent publications such as the "Space Security Index 2017" [1] and "Global Counterspace Capabilities: An Open Source Assessment"[2], both highlight the growing cyber-threat to space assets. Meanwhile, the reality of economic pressures for "pooling and sharing" space based capabilities and communication capacity across the European Union, creates higher levels of demand for security of commercial space operations.

In view of the growing threat, the RHEA Group, in collaboration with the European Space Agency (ESA) and the Belgium Science Policy Organization (BelSPO) have taken steps toward improving the security and resiliency of space systems. To further advance the state-of-the-art of security and resilience of space assets, the RHEA Group has entered an agreement with ESA to establish the Cyber Security Centre of Excellence (CSCE), based at the European space Security and Education Centre (ESEC) in Redu, Belgium. Sponsored by BelSPO the mission of the CSCE is to become the international enabler for security analysis of space systems and related critical infrastructures. Meanwhile, the European Space Operations Centre (ESOC) has initiated a project to enhance security requirements analysis and risk assessment of software in space systems. As part of these mandates, RHEA has initiated development of tools to support "security-by-design" for space systems which are intended to enable system security engineering as a discipline in a concurrent design process.

This paper will summarize the concepts and benefits of the Security Engineering Support Tool (SEST) and Security Aware Concurrent Design Platform (SA-CDP) projects as a domain specific tools supporting a concurrent design process applied to development of space systems and solutions. SEST is an ESOC project, developed by RHEA, to enable security requirements analysis and risk assessment in complex space systems software. Meanwhile SA-CDP expands the SEST concept to provide risk assessment support across an entire space assets system and software life-cycle..

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Artificial Intelligence for Early Design of Space Missions in support of Concurrent Engineering sessions

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1. Introduction

Pre-feasibility and feasibility studies outputs are the first steps of a space mission development. This is the step when experts are encouraged to consider several design options with a certain creativity margin, select input parameters, balance trade-offs and eventually take decisions that will impact the whole design of the mission. At the era of Big Data analytics space mission design could benefit from computational intelligent methods to capitalise on previous, present and future studies and lessons learned to support experts in this design process.

This paper describes the early stages of the development of an ontology based Cognitive Assistant (CA), also called Design Engineering Assistant (DEA) for the preliminary design of space missions in support of concurrent engineering sessions. Figure 1 displays the preliminary architecture of the tool. CAs, decision support tools based on computational intelligence methods and extensive knowledge bases (i.e. formal ontologies), have the potential to enhance the productivity of human experts by providing new insights on large amount of data accumulated in their field. CAs are already successfully being used in the aeronautical, automobile, agricultural, legal and medical fields. However, in the space field few or only incomplete ontologies have been manually developed so far.

In the frame of this study automatic or semi-automatic ontology learning techniques are applied to build a complete space mission ontology taking advantage of accumulated unstructured and structured data from the space domain. The primary targeted users are space systems and subsystems experts taking part into concurrent engineering studies. The DEA will interact with the users via a natural language interface and use machine learning methods to improve its answers to the users' queries.

This paper presents how a cognitive assistant could support space systems experts, whether by relieving their workload, by allowing them to capitalise on pasts designs and lessons learned or by providing hints of alternative design. The DEA will help the experts to not only rely on their own knowledge but also beneficiate from all the accumulated expertise from the space mission design field. This intelligent agent is not intended to substitute the human but rather to enhance her/his perception of different design alternatives and past decisions outcomes. Beyond the technical challenges the DEA must also prove its reliability and trustworthiness to the experts. The intelligent agent has to find its place into the experts' work habits.

1. Figure

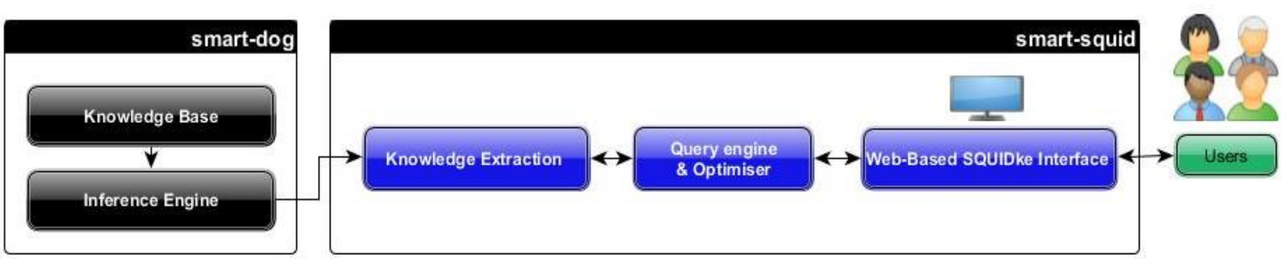

Figure 1: DEA Preliminary Architecture

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CDP4 Additional Software Development: Matlab Application For Database Interactions

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Introduction

Skoltech Concurrent Design Facility (also known as Concurrent Design Engineering Lab – CEDL) has been established and operating ([1] – [3]) since 2014. This work has been built based on previous experience developed at the Space Center in the Ecole Polytechnique de Lausanne (EPFL) [4] – [6].

Concurrent Design Frameworks (i.e. CDP4, Model Centre) depend heavily on domain specific tools. Space domain requires a number of engineering suites to be used for mechanical (i.e. SolidWorks, CATIA), thermal (i.e. ANSYS), control (i.e. MathWorks Matlab©), celestial mechanics (i.e. AGI STK, GMAT) and other disciplines. For the moment, most Concurrent Design tools have poor interface connections with domain-specific tools, hence the learning curve for Concurrent Design is steep and overall process takes longer time.

Work aims and approaches

In this work the development of the CDP4 – MathWorks Matlab© interface plugin is presented. The add-on was developed using different methods of interactive .NET library access in MathWorks Matlab© programming environment. This plugin allows to bring all the main functionality of the C# CDP4-SDK (Software Development Kit) to MathWorks Matlab©, meaning that functions for data transfer from a specific workspace in MathWorks Matlab© directly to the database operated by CDP4 are created directly inside of the MathWorks Matlab© programming environment. The goals of this work were:

1. the development of MathWorks Matlab© application itself for easy data transfer

2. improvement of C# CDP4-SDK for the plugin needs.

Moreover, a similar approach can also be utilized for other domain-specific software systems such as Solidworks and STK.

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A prototype tool for the robust design optimisation of space missions

M. Marchi[1], P. Vercesi[1]; G. Filippi[2]; C. Ortega Absil[2]; A. Riccardi[2]; M. Vasile[2]; C. Poloni[1,3]

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1. Abstract

We present a prototype tool developed to efficiently estimate the propagation of epistemic uncertainties in space system models and to enable the design optimisation with the goal of minimising the uncertainty impact on system budgets. The prototype exploits advanced methods for Evidence-Based Robust Optimisation (EBRO) [1,2,3]. The target application is the preliminary design of systems, subsystems and components, as it is in the initial design phases that epistemic uncertainties (due to a lack of knowledge rather than to a probabilistic description of random phenomena) play a crucial role. Most of this work was done under an ESA-funded Innovation Triangle Initiative ("Demonstration of feasibility and use") project.

The methods proposed, based on Evidence Theory (ET), are an alternative to the standard margin approach. In ET uncertainty can be quantified with two complementary measures: Belief (Bel) and Plausibility (Pl), which represent the lower and upper probability that an event can occur under the available evidence [4]. These measures can be used for a worst-case scenario optimisation of the overall system and for a rigorous quantification of the design margins, because Bel and Pl indicate the lower and upper probability that the design budgets will be as expected at the end of the design process once the design parameters are known exactly. Bel and Pl are computed using intervals of uncertainty with associated values of belief. Their computation with a straightforward application of ET grows exponentially with the number of epistemic uncertainties and can become soon prohibitive. Thus, efficient methods were implemented to reduce the computational cost [1,2,3]. These methods provide conservative estimates of Bel and Pl.

The prototype is a module of the multi-disciplinary optimisation and integration software modeFRONTIER [5]. The module extends modeFRONTIER numeric libraries with algorithms for min-max optimisation, min-min optimisation, and reconstruction of Bel and Pl curves based on evidence-based network models. The resulting tool provides a dedicated user interface and exploits all the features already available in modeFRONTIER to promote the automation of the design simulation process and facilitate data analysis.

In this article, we show the validation of the tool on a simple but illustrative model: the sizing of a nanosatellite composed of three subsystems (attitude and orbit control system, electrical power system and telemetry and telecommand) [6]. As design budget we chose the total mass. We started from a min-max optimisation to find the worst-case configuration and then we reconstructed the Bel curve with different levels of accuracy. Through a sensitivity analysis we were able to further simplify the model by reducing the number of epistemic variables and obtained consistent results for the reconstruction of the Bel curve.

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Nexus: a Process Integration and Design Optimisation Solution

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1. Introduction

The development of modern engineering products requires complex design interactions, team working and computationally intensive analysis tasks. In this scenario, integrated design processes are becoming more and more relevant in the earlier design phases to interactively explore and compare multiple solutions so to identify the most promising ones and to lead to an overall optimal design.

Such integrated processes should account for multiple disciplines ranging from the purely engineering fields (structures, fluid dynamics, systems, controls, etc.) to cost and production considerations.

Nexus, the Process Integration and Design Optimisation Suite by iChrome, has been designed to accomplish these tasks and to answer these needs in an intuitive and user-friendly working way.

This work is intended to provide a general and simple introduction to Process Integration and multi-disciplinary Optimization, showing some of the benefits such integrated technologies can offer to leading industrial firms. Nexus will be used as an example to go through simple applicative examples and to derive some preliminary conclusions on the benefits of the technologies along with some open discussion on the work undergoing at iChrome to make such technologies more distributed and collaborative.

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DAY 2

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 5 – Systems & Concurrent Engineering Methodology Evolution & Trends

09:30 How do you go from a mission concept idea to a NASA selected mission? Formulating the Psyche Discovery Mission with JPL's Concurrent Engineering Teams

K. Case[1], L. Elkins-Tanton[2], A. Nash[1], D. Oh[1], and J. Ziemer[1]
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09:50 A Through-life, Integrated and Concurrent Engineering Methodology for the Responsive Development of Large and Complex Space Systems

P. Gaudenzi[1], M. Lisi[2], G. Palermo[1], L. Pollice[1]
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10:10 Knowledge-Based Information Extraction from Datasheets of Space Parts

F. Murdaca[1], A. Berquand[1], K. Kumar[2], A. Riccardi[1], T. Soares[3], S. Gerené[4], N. Brauer[5]
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How do you go from a mission concept idea to a NASA selected mission? Formulating the Psyche Discovery Mission with JPL's Concurrent Engineering Teams

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The JPL Office of Formulation provides continuity of support and access to domain experts as Principal Investigators mature mission concepts from "cocktail napkin" ideas to Preliminary Design Reviews [1]. Using NASA's Psyche mission as a case study, we will examine JPL's concurrent engineering A-Team and Team X support to the Psyche proposal team in the areas of

1. Science Feasibility
   - Payload Trade Space Exploration
   - Spacecraft Point Design and Cost Estimate
   - Science, Technical, Management, and Cost Review
   - Strategy and Communication Development

Psyche started as a grassroots idea in our A-Team facility, known as Left Field; and in less than five years was selected as a mission under NASA's Discovery Program. While Psyche had a dedicated concept development team, they utilized JPL's concurrent engineering teams, methods, tools, and experts throughout their mission concept lifecycle. This presentation will describe those touch points, i.e., the Psyche customer interactions with JPL's concurrent engineering teams.

From the NASA press release on January 4, 2017, *"The Psyche mission will explore one of the most intriguing targets in the main asteroid belt – a giant metal asteroid, known as 16 Psyche, about three times farther away from the sun than is the Earth. This asteroid measures about 130 miles (210 kilometers) in diameter and, unlike most other asteroids that are rocky or icy bodies, is thought to be comprised mostly of metallic iron and nickel, similar to Earth's core. Scientists wonder whether Psyche could be an exposed core of an early planet that could have been as large as Mars, but which lost its rocky outer layers due to a number of violent collisions billions of years ago. The mission will help scientists understand how planets and other bodies separated into their layers – including cores, mantles and crusts – early in their histories."*

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A Through-life, Integrated and Concurrent Engineering Methodology for the Responsive Development of Large and Complex Space Systems

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Future space systems will be large and complex infrastructures, requiring large initial investments, very expensive to operate and maintain, meant to last for long periods of time (decades). Examples are the systems for PNT, Earth observation and telecommunications based on constellations of satellites, as well as projects to establish permanent bases on the Moon and on Mars.
Three features are becoming key to the success of these future, service-oriented space projects: affordability, supportability and sustainability. They focus the attention of systems engineering on an optimization of the through-life performance.
Concurrent Engineering (CE), performing real-time multi-domain and multi-purposes design, improving trade-space exploration and enlarging the traditional design boundaries, is a very effective way to obtain valuable high-end products. The importance of a concurrent approach in the preliminary, conceptual design of a space system, assessing feasibility from the technical, programmatic and sustainability points of view, is now widely recognized. So far, however, the focus of CE has been mainly centered on the initial design phase, where indeed the most critical architectural trade-offs are performed. To properly face the challenges of future projects, the space industry should adopt a "Through-life Integrated Concurrent Engineering" (TICE©) approach:
1. ***Through-life***: all phases of a space system business are covered (including design and manufacturing, launch, operations, maintenance, service provision and disposal), not just system development;

- ***Integrated***: all disciplines and expertises are integrated in a systemic perspective. All actors (systems architects, designers, MAIT experts, product assurance, management, upstream and downstream functions, supply chain, ...) and stakeholders of the "extended" enterprise are cooperating towards the common objective;
- ***Concurrent***: concurrent and collaborative approaches (with trust and sharing values) and technologies (IT) are widely adopted;
- ***Engineering***: all aspects of the enterprise are engineered and optimized with a holistic development perspective.

Therefore, concurrent and collaborative engineering methods need to be implemented in a more integrated and holistic way and with a through-life perspective, as TICE© approach does. Moreover TICE© methodology might realize, even in the commercial sector, the often chased but never fully achieved, objective of a responsive space industry for responsive and timely delivered large and complex space systems.
As a matter of fact, effective, efficient and flexible design methodogies permit to responsively address very different missions, with optimal choices as far as system architectures and adopted technological solutions are concerned. In the final paper the effectiveness and flexibility of the TICE© methodology, integrating Systems Engineering and Systems Architecting best practices, will be addressed in detail. This methodology is presently being applied to some case-studies in which a responsive development is required, such as the optimization of satellite constellation systems and the design of innovative additive-manufactured space systems.
The TICE© methodology was developed in the frame of the Master in "*Satellite Systems and Services*", organized by the University of Rome "La Sapienza". Integrating CE and through-life perspective (comprising operational, maintenance and disposal considerations) with collaborative approaches and large-scale production best practices, it will help the space industry facing the challenges posed by present and future large and complex space systems.

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Knowledge-Based Information Extraction from Datasheets of Space Parts

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1. Introduction

Selection of the right space parts is an essential step during the design of complex engineering systems and requires information that is typically embedded in unstructured datasheets. Searching for and through component datasheets is an arduous task, requiring significant manual effort. This often results in an incomplete overview of the components available on the market and suboptimal, if not erroneous, design choices.

To tackle the problem of finding the right space parts, the founders of satsearch have embarked on a mission to consolidate global space supply chain information within a single platform. Satsearch has undertaken manual effort to collect, curate, and structure supply chain information by extracting attributes from unstructured datasheets and generating equivalent machine-readable, human-readable, electronic datasheets (EDS). Their vision is to ultimately change the way supply chain information is exchanged across the supply chain by "reinventing the datasheet". Currently however, the company faces a large hurdle of parsing unstructured PDF datasheets, in order to insert consistent and reliable data into EDS format; a task that has been largely manual to date. Due to rapid growth of the datasheet collection, this workload has been rendered unfeasible using the manual technique. Hence, a new approach is necessary to speed up this process.

Datasheets are provided by suppliers to communicate information about products that they wish to sell. These datasheets typically contain information that do not follow any standardization, especially in the space field. Datasheets for comparable space parts often provide different attributes, with no standardized schema in place. In some cases, attributes with the same name can refer to different properties of the system. (e.g., the "mass" for an on-board computer might refer to the motherboard only or to motherboard and structure that encapsulate it). This characteristic of datasheets makes the parsing process more complex. Moreover, some information is not provided in the form of numbers and text, but using graphs and equations.

The solution presented in this paper to speed up the parsing pipeline is a knowledge-based information extraction tool to extract reliable data from unstructured datasheets. A formal ontology, also known as knowledge base, is able to capture the different concepts referring to the same entity, it allows to quickly and accurately identify similarities and relationships between concepts, it can be dynamically enriched, it allows automation of the process and reasoning thanks to the rules inside it. Manual generation of such ontology is a long process that requires a lot of time and domain knowledge, especially when the amount of data is continuously increasing. Therefore, the solution would be to rely on ontology learning techniques that can automate the process.

This solution is currently under development in the frame of a Design Engineering Assistant for Early Space Mission Design. In the frame of this project, the corpus of documents cannot be generated only by datasheets because the semantic knowledge relative to a concept is not present. Therefore, the corpus of documents is enhanced with material (e.g., books) that includes the required knowledge. The comparison of output between manual data extraction by satsearch and the automatic, kowledge-based approach will also serve as a validation step for the DEA project knowledge base generation.

The proposed procedure foresees the creation of a knowledge base for the AOCS subsystem, as starting point, that will be extended to the other subsystems of the satellite. The second step, once the knowledge base is ready, is to use it to extract the structured data needed for satsearch. These data will be compared with the manually extracted ones and assess the potential of automatic parsing and extraction of data.

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Session 5 – Systems & Concurrent Engineering Methodology Evolution & Trends (continued, part 2)

11:05 Responsiveness: New value creation approach for earth observation mission and the introduction of a Japanese program as an implementation example
S. Shirasaka[1], *T. Tohara[1]; T. Obata[2]; S. Nakasuka[2]; M. Arai[3]; T. Imaizumi[3]*
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11:25 Rapid, Comprehensive, Mission Architecting at the Jet Propulsion Laboratory
A. Nash
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, United States of America

11:45 The challenges of designing space systems in the context of System-of-Systems Application
B. Pigneur, *B. de Patoul*
University College London, London, United Kingdom

12:05 Multistakeholder Negotiation space exploration: A Concurrent design methodology to effectively guiding group decision making to balanced preliminary design solution

L. Franchi, *S. Corpino*
Politecnico di Torino, Torino, Italy

Responsiveness: New value creation approach for earth observation mission and the introduction of a Japanese program as an implementation example

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1. Introduction

Currently, Earth observation missions are evaluated by geospatial resolutions and/or time resolutions. Typically, a large observation satellite system has a high geospatial resolution. However, the time resolution is low because the number of satellites is small (i.e., one, two, or three). Meanwhile, a small satellite system has a lower geospatial resolution and a higher time resolution than those of a large satellite system. We propose another evaluation criterion, i.e., "responsiveness" for the Earth observation mission. Currently, "responsiveness" is indirectly investigated. The higher time resolution consequently results in the better responsiveness. However, by utilizing the state-of-the-art technology, we can focus more on the responsiveness and new values can be created. Herein, we define "responsiveness" and propose methods for its improvement. Subsequently, we introduce a satellite program funded by the cabinet office of Japan. In this program, we are developing a small synthetic aperture radar satellite system for on-demand observation.

2. Responsiveness

2.1. What is responsiveness?

"Responsiveness" is a performance measure that indicates the time taken to provide information regarding a situation after its occurrence. For example, if flooding occurs at a certain point of a river and it requires one hour to provide the information of the flood to the stakeholders, the responsiveness is one hour.

The time information provided consists of the following:

- Time to recognize a situation and instruct a satellite to capture an image
- Time to wait for a satellite to arrive to the area to capture an image
- Time to downlink the capture data to the ground
- Time to process the downlinked data and develop information
- Time to provide the information to the stakeholders

2.2. Our approach for better responsiveness

We employ a three-step approach to achieve better responsiveness. The first step is to utilize a deep-learning technique to process the downlinked data to develop information. The second step is to utilize an on-board deep-learning technique. This represents an edge computing concept. A satellite is an edge. We upload the learned deep-learning network to the satellite, which then captures an image and develops the information using on-board deep learning. We can eliminate the time to downlink the captured big data to the ground. The third step is to utilize a ground-based sensor network, which can monitor and capture the situation and trigger information, and send the information to the satellite via Inmarsat and/or iridium. The satellite then automatically plans to capture an image. Thus, we can eliminate the time to recognize a situation and instruct a satellite to capture an image.

3. Small Synthetic Aperture Radar Satellite System for On-Demand Observation

The Cabinet office of Japan has funded a technology-driven innovation program, "ImPACT," which stands for "Impulsing Paradigm Change through Disruptive Technology Program." The objective of the program is disaster monitoring. Under this program, we are developing a small synthetic aperture radar (SAR) satellite system that is capable of on-demand observations. The weight of the first demonstration satellite is 135 kg. The X-band SAR is selected to achieve a 3-m resolution from a 600-km altitude.

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Rapid, Comprehensive, Mission Architecting at the Jet Propulsion Laboratory

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One of the first multi-disciplinary optimization challenges a mission concept faces is finding an initial system level architecture that simultaneously satisfies the constraints of cost, the requirements of science, and the capabilities of engineering.

Compounding this challenge, especially in the early formulation of an architecture, is communicating amongst all key stakeholders where in this multidimensional space of constraints and requirements the current architecture is not yet adequately defined, or if it is defined, is broken.

Recently, Team-X at the Jet Propulsion Laboratory undertook an effort to improve both the speed and comprehensiveness of initial system level architecting.

We will report on the process and tools that have led to a factor of two improvement in the speed of development of the engineering architecture while also comprehensively considering scientific performance and cost.

Our results indicate that a single screen visualization dashboard and cost allocation tools are two of the keys to this speed and comprehensiveness improvement. The third key is system level analogy databases and parametric relationships for system technical capabilities and their technical resource (Size, Weight, Power, etc.) and financial resource (cost) requirements.

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The challenges of designing space systems in the context of System-of-Systems Application

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1. Introduction

In the context of New Space or Space 4.0, there is a potential shift of paradigm towards a system-of-systems (SoS) approach instead of traditional space systems. Growth in the commercialisation of space outside the traditional applications can bring new opportunities in the design of space systems but this also come with challenges as highlighted in Jamshidi's book [1]. The benefits of system-of-systems for space applications is outside the scope of this paper as well as the design of such SoS. However, this paper will focus on the challenges associated with the design of space systems that are intended to be integrated within a larger SoS.

2. Relevance of the research with respect to the conference Thematic Areas

The paper will discuss the current state of the research undertaken at University College London (UCL) and will present progress made towards a methodology. The purpose of this paper is to contribute to the Thematic Area of Processes & Methodology as well as engaging with the community.

In the recent years, many processes and methods have been studied to address the lack of system-level maturity [2], [3] and [4]. The need for an assessment framework has been recognised [5]. Recently, the idea of Concept Maturity Levels (CML) has been introduced [6]. Similarly, this paper recognised the need for a System Maturity Levels and aims to contribute towards the definition of it.

3. Discussion

3.1. System attributes

The first aim of this paper is to establish a list of attributes that can form the basis of the metrics for the system maturity assessment process. Similar to the well-established attributes for Technology Readiness Levels (TRL), there is a need for specific system attributes. These attributes are tailored for expressing the adequacy of a system to be integrated into a system-of-systems. Some of these attributes are technology lifecycle, integration readiness, TRL, concept maturity, technical risks, cost estimation & risks, project organisation, acquisition, mission development, design maturity… The paper discusses the importance of these attributes in details.

3.2. System maturity assessment

This paper will reflect on the system maturity assessment method for systems that are intended to be used within the context of a system-of-systems. The relationship between system attributes and assessment method will be discussed.

3.3. Systems design process

This paper will then reflect on the adequacy of the current traditional design process, followed by many actors in the space industry, being agencies, private companies or other institutional entities. The need for tailoring the concurrent design process to integrate the specificities of designing for SoS will be discussed in the paper.

4. References

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Multistakeholder Negotiation space exploration: A Concurrent design methodology to effectively guiding group decision making to balanced preliminary design solution

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1. Introduction and problem description

Nowadays, the evolution of space industry to the Space 4.0 era, push the design process towards a multi-stakeholder environment. This entail that new space mission designs must be flexible and adaptable to external interactions, such as economic, political and technical environments. These increased interconnections among stakeholders, increase the complexity of the design process, especially in early phases of the mission lifecycle. Indeed, the main goal of the system lifecycle is to guarantee the balance and satisfaction of involved stakeholder's needs. Unfortunately, it is during these early phases that, not only the knowledge about the mission but also the effects on decisions outcomes often are unknown. Moreover, all the decisions taken in these stages are characterized by having delayed lock-in costs associated with them. Finding mutual agreement solutions could reduce the iterations involved in the design process, therefore reducing its costs while increasing its effectiveness. When facing a group decision making, several issues must be considered[1]. Techniques are currently adopted to obtain collaboration among multiple stakeholders, such as team meetings, notices, or information exchange. Nonetheless the proven effectiveness of the collaboration techniques, engineers still spends about 10% of their time in negotiation and it represents one of the most frustrating phases of the design process.

In this current development scenario, before beginning a concurrent design session, it is necessary to have a clear definition of the problem under analysis. This can be obtained thanks to a generation and exploration of design alternatives yet in the initial problem definition. This process must consider that design usually involves various individuals, who take decisions affecting one another. An effective coordination among these decision-makers is critical.

1.1. The proposed new design methodology and Concurrent Design tools enhancement

The paper presents a concurrent design methodology which aims to speed up the evolution of concept maturity from level 1 (born of the idea) to level 7 (integrated preliminary baseline) [2]. This goal can be achieved by an ad-hoc assistance to design experts and, more in general, stakeholders with a generation and exploration of a negotiation space. The negotiated solutions are generated via a multidisciplinary collaborative optimization framework, applying complete or partial information Stackelberg game theory and multi-attribute utility theory, while exploiting artificial intelligence algorithms. The concept of utility function is exploited as mechanism to bridge the language barrier between experts with different backgrounds and differing needs, while use both technical background and subjective needs to generate and to evaluate a multitude of alternatives. Thanks to this guided exploration, the follow-up concurrent design session can begin with a set of negotiated sub-optimal designs. Domain experts are thus able to locally optimize their own domain design starting from a reference point. Therefore, to actively involve domain experts in the loop, the paper presents a graphical user interface which exploits artificial intelligence and local design of experiment to assist the domain experts in their design process, starting from the previous identified sub-optimal one.

To highlight the benefits of the proposed methodology, the paper presents the design of a CubeSat mission for the observation of Lunar radiation environment. At last, robustness analysis, via Epoch-Era method, has been also carried out to assess the value changeability of each negotiated design solution, with respect to changes in the stakeholder preferences. The benefits provided by the proposed design methodology are highlighted, and further development and improvements proposed.

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DAY 2

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Session 5 – Systems & Concurrent Engineering Methodology Evolution & Trends (continued, part 3)

13:45 Towards a Conceptual Data Model for Fault Detection, Isolation and Recovery in Virtual Satellite
S. Müller, *A. Gerndt*
German Aerospace Center (DLR), Brunswick, Germany

14:05 D-CDF: Adapting ESA's Concurrent Design Facility for use in the Defence Sector
J. White[1], *S. Gerené[2]*
[1]The DIG, The Hague, The Netherlands
[2]RHEA Group, Leiden, The Netherlands

14:25 Launching Concurrent Design into the superyacht world
G. Swiers-Sellmeijer
Feadship, Aalsmeer, The Netherlands

Towards a Conceptual Data Model for Fault Detection, Isolation and Recovery in Virtual Satellite

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1. One Page Abstract

In the past years a lot of effort has been invested into enabling Model Based Systems Engineering (MBSE) for the whole life cycle of a spacecraft. Part of these efforts is Virtual Satellite (VirSat) [1], a software framework that allows for the integration of various different engineering processes across the individual phases of spacecraft design and operations, as well as the different disciplines.

An important discipline in the design of safety critical systems such as spacecraft is reliability engineering. No matter how well designed a system is, it must always be able to deal with the presence of faults to some extent. In order to raise trust in handling such faults, concepts from the domain of Fault Detection, Isolation and Recovery (FDIR) are employed.

With this paper we present our approach for bringing MBSE into the realm of reliability engineering using the Virtual Satellite framework. The tool we are developing for this purpose is called VirSat FDIR. Virtual Satellite provides a generic systems engineering language in which a Conceptual Data Model (CDM) capturing one specific engineering aspect can be described, in this case FDIR. For VirSat FDIR we have developed such a Conceptual Data Model, which we discuss in this paper.

The tool currently focuses on the modelling of faults by means of Fault Trees. Fault Tree Analysis is a commonly used methodology for performing state-of-the-art failure analysis [2]. The resulting Fault Trees are acyclic graphs that describe how faults propagate through the components and subsystems of a system and eventually lead to a top level failure. VirSat FDIR supports the graphical modelling of Fault Trees and the import of textural descriptions of Fault Trees for integrating supplier data. Furthermore, it also supports the generation of Failure Modes, Effects and Criticality Analysis (FMECA) tables based on the ECSS standards.

In conjunction to fault modelling, the tool also features modelling support to deal with the recovery related aspects of FDIR. For this purpose we have introduced a concept we call Recovery Automaton that models the underlying decision process guiding which recovery action should be executed upon observing some fault. The tool also implements the synthesis procedure that we have described in [3] that takes as input a modelled Fault Tree and aims to generate recovery strategies optimized towards reliability, in particular focusing on the aspect of redundancy management.

Due to being conceptualized with the generic engineering language, VirSat FDIR can be used to annotate any Virtual Satellite study with fault and recovery information without requiring domain specific knowledge about the models that are being annotated. This also means that the tool can be used as soon as in early phase A feasibility studies as well as in the later phases of the spacecraft life cycle. Furthermore, as Virtual Satellite is made with concurrent engineering in mind, VirSat FDIR inherits this capability and can be employed in parallel to the creation of the system model.

With the initiative of the VirSat FDIR software we not only intend to model FDIR concepts but also actively employ these models to assess the FDIR design and perform verification and validation (V&V) on it. Towards this goal we support performing Reliability Analysis, a quantitative form of analysis that requires precise quantitative information such as the failure rates of the base faults, and Minimum Cutset Analysis, a qualitative form of analysis that only requires the underlying Fault Tree structure.

2. References

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Dynamic Fault Trees. In AIAA SPACE and Astronautics Forum and Exposition (p. 5163).

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D-CDF: Adapting ESA's Concurrent Design Facility for use in the Defence Sector

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Defence capability development projects - especially IT projects - have a much higher failure rate than similarly complex projects run in the Space sector. Despite this, there have been relatively few steps taken by Ministries of Defence, large multinational Defence organizations or industry to make fundamental changes to the way projects are executed. As a result, failures continue at an unacceptable rate, wasting both money and time and reducing military effectiveness.

Taking a closer look at how the Space sector delivers complex projects, some stark differences between Space and Defence are immediately evident. Most notable is the way projects are executed in the earliest stages of requirements identification through to high-level design. In Defence, a documentation-heavy, serial process is typically used, which results in delays, increased costs and a lack of stakeholder alignment, all of which put projects at increased risk. In Space, a more modern approach is used called Concurrent Design (CD) in which all key stakeholders are brought together in the earliest stages of a project to rapidly and concurrently iterate through both the requirements and design until an optimal solution is achieved taking into account a variety of constraints such as time, budget and technical feasibility.

The Defence Innovation Greenhouse (The DIG), RHEA Group and the Dutch Ministry of Defence are undertaking a project to begin to adapt the CD approach being used at the European Space Agency to make it more suitable for use in Defence environments in order to both accelerate and de-risk complex Defence projects. Ultimately, we aim to address three domain areas that are of great interest to Defence leaders within the Defence Concurrent Design Facility (D-CDF) initiative.

The first domain area is project high level design. In this area we aim to adapt existing models used in the Space sector to make these models are more appropriate for use in Defence projects. The goal is to reduce the time required for the earliest phases of Defence project execution and significantly improve the quality of requirements that are provided to industry for implementation. We anticipate that benefits similar to those achieved in the Space sector can also be achieved in Defence, saving money, time and - ultimately - lives.

The second domain area is multinational consensus building on key requirements. One of the greatest challenges in Defence is to have nations come to a common understanding of requirements for Defence capabilities before high level design activities begin. We believe that Concurrent Design principles can be adapted to build models and processes that improve our ability to work with multiple national stakeholders to more quickly reach a common (and documented) understanding of key requirements that can then be fed into the next step, which is high level design.

The third domain area is to use adapted CD models and processes for troubleshooting of Defence projects that have become out of tolerance in terms of time, budget, scope or quality. We believe that the root causes of many project failures share similar characteristics. Because of these similarities, we are confident that an engineering approach can be applied to identify and describe these root causes and develop a set of common solutions over time. Ultimately, we believe that the results of work done to support project troubleshooting can be fed back into both of the other models being developed in order to reduce the occurrence of project failures in the first place.

As we are at the earliest stages of development of the D-CDF, these models have not yet been developed. However, we do have a good grasp on the theoretical underpinnings for the overarching D-CDF program and are prepared to share this with the broader community.

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Launching Concurrent Design into the superyacht world

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1. Concurrent Design @ Feadship

After several years of development and innovation Feadship has opened three state-of-the-art Concurrent Design facilities which allow the different teams involved in a build to simultaneously communicate with owners teams in an interactive way. Developed with the European Space Agency, this revolutionary new methodology facilitates immediate responses to design and engineering decisions, speeding up the process and adding even more innovation flair to each Feadship.

1.1. Unique & complex yachts

As every Feadship revolves around a pure custom build, each is full of unique ideas devised by the owners and their team in partnership with our designers, naval architects and engineers. By its very nature this process has traditionally been a lengthy one as concepts go backwards and forwards in an iterative process between the teams involved.

Feadship owners are demanding increasingly complex custom yachts which place pressure on engineering capacity. The amount of engineering work is also increasing due to our ‘design for production’ strategy, short innovation cycles and an ongoing desire to reduce construction schedules even further.

These factors may potentially result in an increase in both the amount of early design capacity required and the throughput time involved in engineering activity. To tackle these challenges, we partnered with the European Space Agency to find ways to translate its successful concurrent engineering approach into the superyacht world.

2. Collaboration between ESA and Feadship

Together with ESA Feadship started a business case based on three pillars;

- The CD methodology: capture and document the Feadship CD-methodology, taking into account the existing Operational Excellence Program.
- The Typical roles: define the CD roles and ensure connection with the familiar roles within a Feadship project team.
- The CD-facility: Design the layout and set up the program requirements of the CD facility.

3. Current use & Future vision

Since 2016 the methodology of Concurrent Design is implemented and Feadship is on an upward trend. However, the methodology is not fully embraced yet and is sometimes seen as additional work. It is now time to act to get CD as a daily practice within the organisation and show the importance and major benefits of CD.

This paper describes the implementation of concurrent design as a new methodology within Feadship.The paper is divided into two subjects that cannot be seen separately; first the creation and design of the CD facility - at the same time knowing that proper equipment is not a guarantee for a good CD process. Second, the challenges within the CD process and creating the trust of people in this new way of designing a yacht.

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DAY 2

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 5 – Systems & Concurrent Engineering Methodology Evolution & Trends (continued, part 4)

15:40 Low cost space mission trends and approaches in early design phases.
G. Cifani
ESA-ESTEC, Noordwijk, The Netherlands

16:00 Costing at the Speed of Light: How Your Concurrent Engineering Design Team Can Bootstrap Your Organizations Programmatic Capabilities
J. Hihn, *T. Youmans, M. Saing*
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, United States of America

Low cost space mission trends and approaches in early design phases.

G. Cifani

ESA-ESTEC, Noordwijk, The Netherlands

Abstract

During the last decade much more often "low cost mission" have been implemented or studied by national and international agencies, seeing a wide range of mission objectives, from In-Orbit-Demonstration to interplanetary exploration.
These led to an increase in the cadence of missions. Mission cadence is a major enabler of technological innovation and the driver for the training and testing of the next generation of managers, engineers, and scientists.

"Buying a low-cost spacecraft is comparable to buying a family car. We look at our approximate budget, evaluate what is available on the market, and select a car which is some compromise between what we want and what we can afford."[1]

This paper describes recent trends and approaches related to the definition of low cost projects.
In particular, it address aspects such us: requirements definition, achievable performances, standard products utilization and reusability and related impacts on procurement, engineering and product assurance processes.
Moreover, the exploitation of future technological trends (e.g. advanced manufacturing) and commercial products such as CubeSat standard are treated.

Ultimately, this document aim to provide to the reader a compressive picture on trends and approaches for low cost missions definition.

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Costing at the Speed of Light: How Your Concurrent Engineering Design Team Can Bootstrap Your Organizations Programmatic Capabilities

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Developing space missions and especially space science missions presents many programmatic challenges. Foremost is that there are not that many missions from which to learn and that science missions typically have significant unique elements, especially planetary missions. Clearly, it is very difficult to estimate and plan any project with major unique and new elements. So, what do you do when it is necessary to generate at least reasonable cost estimates at the earliest Concept Maturity Levels (CML 1 and CML 2) and you never flew anything like this before? What do you do when you have so few historical data points that they do not span the design-cost parameter space? For example, all of ones past missions are orbiters and now we need to design and cost a lander, a rover, or an orbiter with probes. For organizations with early concept design teams such as JPL's Team X that include cost estimates as one of their products you can 'bootstrap' your available parameter reference set by combining technical and cost parameters from historical actuals, high quality design studies, and winnable proposals into a single database. The data from these not flown concepts have informational value but with greater uncertainty then historical data. They provide insight into technical and cost parameter combinations associated with mission designs that are in the 'ballpark'. This data can be used to improve our ability to estimate cost and technical parameters by providing a source of analogies as well as the ability to develop, calibrating and with the actuals validating the performance of a wide range of models. Models that use a small number of inputs with wide confidence intervals and model with greater fidelity and tighter confidence intervals. In this paper we will describe (1) the integrated Team X design-costing process, (2) the web-based database that is under development along with how the data is obtained, vetted and processed, (3)m the complete set of analogy tools, rule-of-thumb and parametric models that are maintained, (4) how everything plays together nicely (most of the time), and finally (5) the algorithms and methods used to enable combining data from different sources. Most of what is described is to varying degrees reproducible in other organizations.

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DAY 2

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Poster Session

P1 System design synthesis and multi-disciplinary optimization of a conceptual re-entry vehicle using an integrated design process
S. Pate[1*], *L. Rana*[2], *D. Brinkman*[3]
[1] The American Society of Mechanical Engineers, Leuven, Belgium , [2] The University of Texas at Arlington, United States of America, [3] Delft, The Netherlands

P2 Integrated Design and Simulation Environment for a Space Qualified Onboard Computer
C. Nieto-Peroy[1], *M. R. Emami*[2,3*]
[1]Luleå University of Technology, Kiruna, Sweden, [2]Luleå University of Technology, Kiruna, Sweden, [3]University of Toronto Institute for Aerospace Studies, Toronto, Canada

P3 Efficient Experimental Strategies for Complex Space Simulation System
P. Shi[1*], *X. Peng*[1]. *B Wang*[2].
[1] National Space Science Center, Chinese Academy of Sciences, Beijing, China , [2]University of Aerospace Engineering, Beijing, China

P4 Development and Validation of a CFD optimized integrated Pitot Sensor - Produced by Selective Laser Melting and Abrasive Flow Machining

J. Ferchow[1*], *D. Kläusler*[2], *M. Meboldt*[2]
[1]*Inspire AG, Zurich, Switzerland,* [2]*ETH Zurich, Zurich, Switzerland*

P5 Extensive Cost Estimating methodologies for the CDF GaiaNIR study
E.Lamboglia*, M. Van Pelt, A. Cotuna*
European Space Agency, The Netherlands

P6 ESA Academy CubeSats Concurrent Engineering Workshop
J. Vennekens[1*], *L.Ha*[2], *C. del Castillo-Sancho*[2], *V. Gupta*[3], *M. Schermann*[2], *N. Callens*[4], *J. Vanreusel*[4]
[1]*Telespazio Vega UK on behalf of ESA, Noordwijk, The Netherlands ,* [2]*European Space Agency, ESTEC, Noordwijk, The Netherlands,* [3]*Redu Space Services on behalf of ESA, ESEC-Galaxia, Transinne, Belgium,* [4]*European Space Agency, ESEC-Galaxia, Transinne, Belgium*

P7 New opportunities: exploiting Concurrent Design tools in the Model Based Systems Engineering Approach
A. Ivanov*, A. Platonov, A. Potapov, A. Golkar, D. Knoll*
Space Center, Skolkovo Intstitute of Science and Technology, Moscow, Russian Federation

P8 Leveraging Mbse for Esa Ground Segment Engineering: Starting with the Euclid Mission
D. Fischer[1], *F.Keck*[1], M. Wallum[1], *M. Spada*[1], *T. Stoitsev*[2]
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System design synthesis and multi-disciplinary optimization of a conceptual re-entry vehicle using an integrated design process

S. Pate[1*], *L. Rana[2], D. Brinkman[3]*

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[2] The University of Texas at Arlington, United States of America
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1. Introduction

Designing a space access vehicle traditionally happens in a sequential manner, that is, one step at a time, passing the design from one disciplinary team to another. In this manner, the design goes through several iterations until the requirements from all disciplines are satisfied. The conceptual design phase is generally completed in a few weeks or months, where the main objective of the design concept is the definition of the mission-technology-configuration options that satisfy the customer's requirements. This is achieved by evaluating multiple system design concepts and, eventually, defining the system baseline with subsystem technology, and programmatic and cost assessment. The level of detail increases enormously with the increase in the level of the design phase. Depending on the complexity of the system and the available resources, the detailed design phases may take months to years to fully design the system. From the literature study it is also observed that, although there are significant advancements in the propulsion system, landing mechanism, avionics, and interior of the spacecraft, the aerodynamic shape or vehicle configuration is still scaled or modified with respect to the heritage designs (benchmark designs: Apollo and Space Shuttle). Thus, if a poor configuration is chosen during the conceptual design phase, this will lead to a worse and expensive system at the end of the process. Hence, there is a need for an approach which allows us to explore the complete set of possible configurations rather than directly selecting the benchmark design as a starting point. This paper discusses an innovative approach for the conceptual design of re-entry vehicles.

2. Methodology

In this paper an integrated design process is used, where the user can integrate all the design disciplines on a common platform and perform the feasibility study of the conceptual re-entry vehicle design [1]. Furthermore, an innovative approach of design synthesis is used which allows the user to explore the complete set of feasible vehicle configurations for the given mission and system requirements [2]. Thus, before considering a fixed benchmark configuration of a re-entry vehicle, the user can find the best family of re-entry vehicle configuration as starting point for the specific mission scenario. A parametric solution-space exploration is performed to refine the set of considered configurations. This allows the user to derive the best possible solution set to start the optimization process. In this paper, simultaneous optimization of the configuration and trajectory is performed. The performance of the vehicle is computed using first-order analysis methods for mass budget, aerothermodynamics, thermal protection system, and trajectory design. Thus, this approach allows the user to investigate the best possible configuration for the mission scenario as well as derive the optimized configuration and its respective optimized trajectory to re-enter safely.

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Integrated Design and Simulation Environment for a Space Qualified Onboard Computer

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1. Abstract

This paper presents a simulation facility used for the verification and validation of Onboard Computers. The simulation facility was utilized to test a recently developed Onboard Computer. Particularly, the presented platform aims at the verification and validation of embedded systems rather than control algorithms [1] [2]. The facility consists of a Hardware-in-the-Loop Simulation platform, which feeds the target Onboard Computer with signals coming from various distributed spacecraft components. Such spacecraft components can be either hardware components interfaced with the platform or other systems emulated by the computer running the simulation.

The architecture of the Integrated Design and Simulation Environment (IDSE) is shown in figure 1. Starting from the right end of the figure, there is the programming computer. The programming computer is connected to the Onboard Computer, also known as Spacecraft Management Unit (SMU), through dedicated Ground Support Equipment (GSE). The SMU is in this case the main test unit. The simulation server is connected to the SMU in three different ways to cover all the possibilities of interacting with the test unit, i.e., CAN bus port, SpaceWire port, and power inlet.

In parallel, the simulation includes the models of various subsystems, such as sun sensors and reaction wheels. The simulation computer can interface with a camera that is utilized during the simulation as a navigation camera (NavCam). Additionally, the simulation computer interfaces wirelessly with a training satellite, called EyasSat. Such a satellite is a simplified version of a real satellite, and it includes the most common subsystems present in actual orbiting satellites, such as an attitude determination and control system [3]. Furthermore, the dynamics of such training satellite can be emulated in orbital conditions, since it is mounted on a floating-base, five-degree-of-freedom air-bearing stand. In conclusion, the current setup allows for testing the SMU's functionality by interfacing modelled and actual hardware in an emulated space environment.

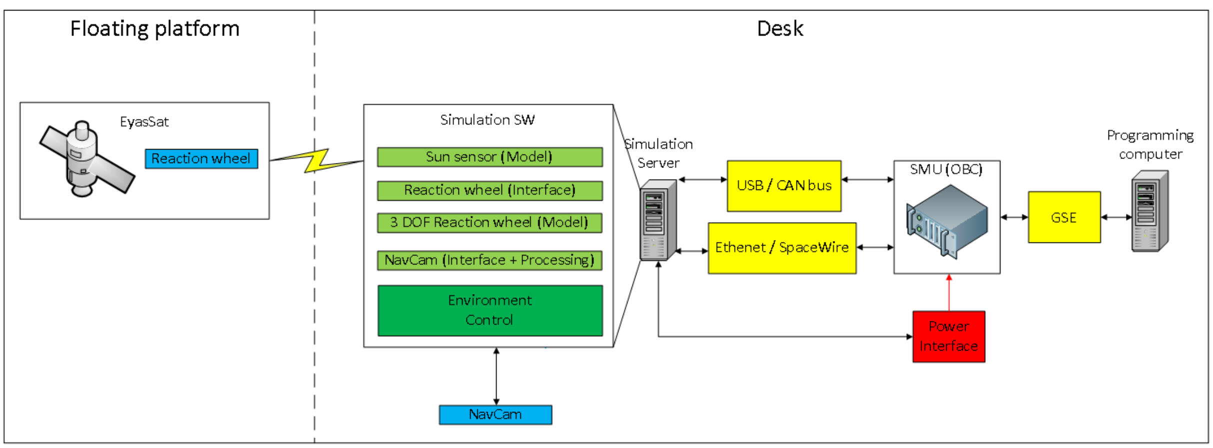

Figure 1: Architecture of the IDSE.

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Efficient Experimental Strategies for Complex Space Simulation System

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1. Introduction

The aerospace system simulation is generally a large-scale simulation system composed of several subsystems. It usually has features such as multiple structural levels, many uncertainty factors, and long running time. For these characteristics, simulation is used to analyze the reliability of aerospace systems, the importance of noise parameters, and the trade-off of solutions for ranking and selection. Models of aerospace systems often depend on multiple inputs such as material properties and forcing terms. In most cases, these inputs are not known exactly due to measurement errors, noise, or small perturbations in the manufacturing processes, and thus they are modeled as random variables with a distribution that accounts for these uncertainties. The output of the model then also becomes a random variable, and one is typically interested in the statistics of the output. The Monte Carlo method evaluates the model at samples drawn from the distribution of the inputs, and estimates the statistics from the obtained outputs. Monte Carlo estimators converge slowly with the number of samples and thus many model evaluations are necessary to achieve a given error tolerance. It is very difficult to simply pursue the improvement of the computer hardware performance, or to directly optimize and improve the process of computer simulation. Therefore, the research objectives are mostly focused on specific efficient experimental methods.

The selection of simulation methods will directly affect the results of system simulation. Excellent simulation experimental methods can effectively reduce the number of complex simulation system experiments and relieve the pressure of simulation calculations. "Experimental efficiency" refers to the number of simulations required to achieve a certain degree of accuracy. Especially for the simulation analysis of complex aerospace systems, with the increase of task complexity and model complexity, the method efficiency of ordinary simulation experiments will be affected. Especially for some simulation models that characterize minimal probability events, even using modern advanced computers may face the situation where the simulation time is measured in terms of years. Researches on how to improve the efficiency of the simulation experiment in the presence of uncertainty is a key and difficult problem in the field of simulation, and it has practical requirements and prospects.

This paper proposes an improved combined simulation sampling method. According to the idea of importance sampling before sampling, first surrogate model is used to construct the biasing distribution in the first step of the Monte Carlo method with importance sampling and samples are drawn from the biasing distribution to derive an estimate in the second step. Then, importance function is subjected to Latin hypercube sampling to ensure that the sampling points are evenly distributed throughout the sampling layer to avoid sampling the samples that have been extracted, resulting in a large number of repetitive sampling and reduction in sampling. effectiveness. Finally, if the statistic function is monotonously non-decreasing with respect to each variable, on this basis, the variance of the statistic can be further reduced by using the technique of dual random variables. The numerical results demonstrate the runtime savings on linear and nonlinear problems, and the feasibility and effectiveness in improving aerospace simulation efficiency.

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Development and Validation of a CFD optimized integrated Pitot Sensor - Produced by Selective Laser Melting and Abrasive Flow Machining

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Additive manufacturing (AM), offers the possibility to produce complex internal structures that are otherwise difficult to manufacture. In particular the powder bed based and layer by layer process Selective Laser melting (SLM) offers a large design freedom for internal structures. The limitation here is still the rough surface quality of the SLM parts. The surface needs to be smooth and should show a low surface roughness to avoid sticking rest powder and to ensure good flow characteristics, in order to use it for gas applications in aerospace industry. Hence a suitable post-processing procedure is needed to smooth the rough surface of internal SLM structures.
In this paper, a lightweight volume flow sensor was sought which can be integrated into an existing SLM valve design. In addition, the sensor is selected in a way that the surfaces of the internal structures can be post-processed. As a measuring principle, a pitot tube was determined, plotted in Figure 1, which was subsequently constructed in two printing directions. The abrasive flow machining (AFM) process should be used as a post-processing method. Based on a CFD analysis, the measuring sensor design was therefore flow optimized in order to obtain a regular removal by the AFM.

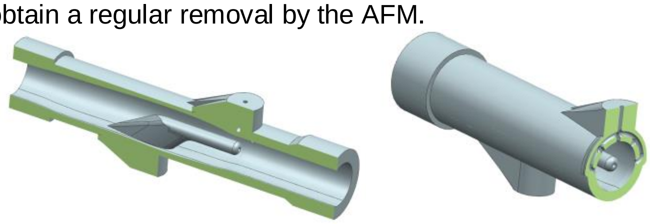

Figure 1: Horizontal oriented integrated pitot tube.

The optimized sensor design was then manufactured using selective laser melting (SLM) and post-processed with the mentioned AFM. With the help of a test bench, the pressure loss and the volume flow were measured. The results of the developed sensor were compared with an established sensor and further validated, plotted in Figure 2.

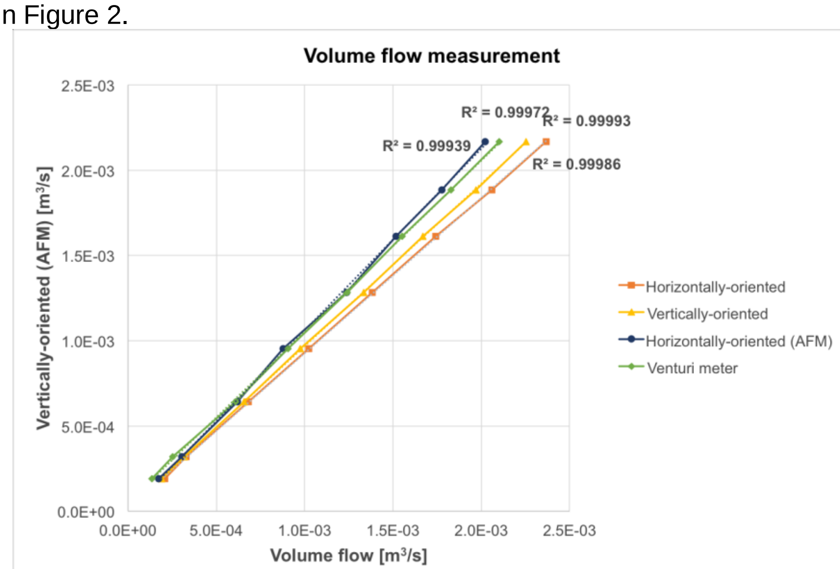

Figure 2: Volume flow measurement results.

The results of the volume flow measurement show that the chosen measuring principle is suitable for AM in particular for SLM. Furthermore, the surface roughness can be improved by the AFM post-processing.

Extensive Cost Estimating methodologies for the CDF GaiaNIR study

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1. Introduction

In the frame of the GaiaNIR Concurrent Design Study, this paper shows the wide range of cost estimating methodologies adopted at various stages of the study, converging to the final programmatic assessment. The main objective of the appointed cost chair was "design-to-cost" and evaluation of the compatibility of the CDF GaiaNIR concept with respect to the Cost at Completion budget constraints. Thanks to strong similarities with the ESA Gaia mission, the estimate exercise for the CDF GaiaNIR study could start with a bottom up approach, which is very unusual for the type of early estimates performed in pre-Phase A stages. This exercise continued evolving with a wide range of methodologies and a series of analyses for which the required details are usually not available during CDF iterations. Detailed knowledge of the Gaia design, the participation of the (former) Gaia project team to the sessions, in combination with access to the project cost details allowed to perform a very complete programmatic evaluation.

This paper describes the estimating process, the procurement approach consistently with geo distribution assumptions, as well as the various cost and related system-engineering considerations: obsolescence due to the considerable time gap between Gaia and GaiaNIR and its impact on the implementation schedule, major science requirement differences between the two missions, equipment capabilities evolution, and various cost reduction options.

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ESA Academy CubeSats Concurrent Engineering Workshop

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1. Abstract

The Training and Learning Programme [1] is one of the two pillars of the ESA Academy programme [2] for university students of ESA Member and Associate States. It aims at complementing the standard academic formation in space-related disciplines by transferring knowledge, know-how, and standards from specialists to university students through training sessions. Within its portfolio, the Training and Learning Programme offers learning opportunities to university CubeSat developers with the objective to help them close the gap between mission concept and CubeSat design.

One of these sessions is the 'CubeSats Concurrent Engineering (CE) Workshop' [3], developed and delivered in collaboration with engineers of ESA's main Concurrent Design Facility (CDF) [4], with the objective to introduce students to the concurrent design methodology applied to a CubeSat mission. The workshop is aimed at better preparing university teams which are either starting a new CubeSat project or working on the early stages of one (conceptual and/or preliminary phase of their CubeSat design). To support the Training and Learning Programme and deliver the different training sessions, the ESA Academy's Training and Learning Facility, a dedicated training room and educational CDF similar to the one at ESTEC, has been developed at the ESA Education Training Centre in ESEC-Galaxia, Belgium.

As a first step of the CubeSats CE Workshop, university students are introduced to the CE methodology and the Open Concurrent Design Tool (OCDT) software package [5]. The background of the study is then presented in the form of mission requirements by the ESA system engineers. For the CE sessions, students are divided into groups and assigned to one discipline (e.g. systems engineering, mission analysis, power). Guided by ESA system engineers, students identify design drivers and create subsystem concepts. From these analyses different concepts arise, and trade-offs are performed of each design solution. They jointly work on the function and product trees and establish the first budgets. After several CE iterations using OCDT, the final concept design is presented by the students to the ESA experts.

Complementary to the CE sessions, dedicated CubeSat lectures provide an enhanced understanding of nanosatellites among students. For the pilot edition, topics covered were CubeSat architecture and reliability; ESA's CubeSat activities; mission analysis; and advice and technical know-how from the Fly Your Satellite! (FYS) programme, ESA Academy's educational CubeSat programme [6]. Participation in the workshop is an excellent starting point to get familiar to CubeSat projects and for a possible future application to the FYS programme. FYS is aimed at student teams that are close to or have already consolidated their CubeSat detailed design and are interested in receiving ESA's support during the manufacturing, assembly, integration, testing, launch, and operating phases of their mission.

The pilot edition of the CubeSats CE Workshop was held between 16-19 January 2018. Participating students were part of a number of CubeSat teams from ten different universities of ESA Member and Associate States. Students reportedly learned how to perform the preliminary design of their CubeSat mission, gained a foundation on requirements management and its relation to spacecraft design, finding the CE approach beneficial to the design of their own mission.

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New opportunities: exploiting Concurrent Design tools in the Model Based Systems Engineering Approach

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Skoltech Concurrent Design Facility (known as Concurrent Design Engineering Lab – CEDL) has been established and in operation ([1]–[3]) since 2014. This work builds on previous experiences developed at the Space Center in the Ecole Polytechnique de Lausanne (EPFL) [4]–[6]. The next steps for the process are in closer integration of techniques in the academic process in the Master in Space and Engineering Systems. In this paper, we will outline the flow of students in our program through the V-diagram, starting from project formulation and stakeholder analysis all the way to implementation and operation of the system. We have also developed relationship with Russian space and aviation industry, however, the road to technology transfer will be difficult.

Concurrent design approach has already found its way into educational practices of many universities. With support of the technological headquarters in ESTEC, educational facilities have been established in ESA Education center in Redu. There is a number of classes offered to students train in tools, approach and procedure. Notable events include PostAlpbach sessions in the fall of 2016 and 2017.

At Skoltech, we aim to give students an experience with full cycle of systems engineering starting from mission formulation and stakeholder analysis, through concurrent design and multidomain optimization (MDO) to introduction to Product Lifecycle Management (PLM), creation of prototype and its operation. The process includes a number of classes (Fundamentals of Systems Engineering, Spacecraft Mission Analysis and Design, Space Sector course and others) as well project oriented activities. During two years of the master program, students participate in a variety of project following CDIO (Create Design Implement Operate) principles culminating in Master thesis. Normally, these projects are implemented as a part of long term projects implemented in the Skoltech Space Center. Currently, MBSE approach is applied to projects related to a small remote sensing drone, stratospheric observation platform and small satellite constellation for scientific purposes.

Both European and Russian industry needs students educated on principles of Model Based Systems Engineering. This approach aims to replace current document cycle with version controlled models that follow the project during all phases. Additionally, Russian government has announced a number of initiatives related to “Digital Economy”. MBSE approach is a perfect industrial application to support renovation of Russian industries. We will also discuss recent significant events in tooling and especially open source projects CEDESK, CDP4 and OpenMBEE [7], [8]. Finally, we will conclude how university processes can drive industrial development, fueled by open source software.

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Leveraging Mbse for Esa Ground Segment Engineering: Starting with the Euclid Mission

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3. Introduction

The development of a mission Operations Ground Segment (OGS) is a complex systems engineering activity that follows applicable standards and best practices. It is interconnected as part of a system of systems with other developments, such as that of the space segment or the science ground segment. The OGS supports a large number of system-level processes, utilising functional components and interfaces to fulfil specific tasks. The overall goal of the engineering activity is to design, integrate, verify and validate all of these in order to satisfy the provided mission requirements. This is performed in alignment with an associated mission operations concept which utilises the system-level processes to maintain and operate the system throughout its lifetime.

The OGS systems engineering approach currently in place is very document-centric i.e. based on a large number of documented deliverables and document reviews. These can easily suffer from redundant and inconsistent contents as the system development lifecycle progresses. The execution of OGS engineering tasks is thus rendered unnecessarily complex, time-consuming and prone to human error or oversight. In this paper, we discuss further shortcomings of the current document-centric approach to this activity and introduce the initiative taken by the European Space Agency to improve on this by adopting a Model-Based Systems Engineering (MBSE) paradigm.

Our approach to MBSE is a bottom-up one that is conceptualized around the need of the OGS systems engineer. This means, the complexity of MBSE, in particular the underlying data model and associated language, is abstracted as much as possible in order to avoid steep learning curves, the need to hire specialized architects to translate between the engineer and the model, and a low initial return on investment. The supporting framework adheres to an ‘as simply as possible, as complex as necessary’ concept. We are currently in the process of developing this approach into a paperless OGS engineering framework through a study activity in the context of the Euclid mission.

This paper is a revised and shortened version of the American Institute of Aeronautics and Astronautics (AIAA) publication of the same title [1], submitted in full agreement with the authors and publishing entities.

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DAY 3

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 6 – Concurrent Engineering – Academic Perspectives

09:00 CDF as a tool for space engineering master's student collaboration and concurrent design learning
J. Bermejo, *J.M. Álvarez, P. Arcenillas, E. Roibás-Millán, J. Cubas, S. Pindado*
Instituto Universitario de Microgravedad 'Ignacio da Riva', Madrid, Spain

09:20 The Spanish contribution to the 1st ESA Concurrent Engineering Challenge: design of the Moon Explorer and Observer of Water-ice (MEOW) mission
E. Roibás-Millán, *F. Sorribes-Palmer, M. Chimeno-Manguán,* J. Cubas, *S. Pindado*
Instituto Universitario de Microgravedad 'Ignacio da Riva' (IDR/UPM). Universidad Politécnica de Madrid, Madrid, Spain

09:40 Overview and Results of the Inaugural ESA Concurrent Engineering Workshop Dedicated to CubeSats and the Subsequent Applications and Implementation for a University CubeSat Design Project
L. Brewster
Carleton University, Ottawa, Canada

10:00 ESA Academy ‘s Concurrent Engineering Workshops
J. Vennekens[1], *N. Callens[2], R. Biesbroek[2], A. Cotuna[2], H.P. De Koning[2], J. Huesing[2], M. Scherrmann[2]*
[1]Telespazio Vega UK on behalf of ESA, Noordwijk, The Netherlands , [2]European Space Agency, Noordwijk, The Netherlands

10:20 Introducing the Australian National Concurrent Design Facility – UNSW Canberra’s end-to-end mission design tool
J.-C. Meyer, *D. Griffin*
UNSW Canberra, Canberra, Australia

CDF as a tool for space engineering master's student collaboration and concurrent design learning

J. Bermejo, *J.M. Álvarez, P. Arcenillas, E. Roibás-Millán, J. Cubas, S. Pindado*

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Abstract

The IDR/UPM Institute (*Instituto Universitario de Microgravedad 'Ignacio da Riva'*) established a Concurrent design Facility (CDF) in 2011. This facility is used primarily for academic purposes within the Master in Space Systems (MUSE) that the same institution organizes. This CDF is based on the Open Concurrent Design Tool (OCDT) from ESA, which allowed a group of students from the master to participate in the Concurrent Engineering Challenge organized by ESA Academy in September 2017.

Since the creation of this facility, the development of tools and utilities for space mission design has been mostly conducted by students under the direction of professors. At present, master students are building a set of models of the main spacecraft subsystems to study space missions beyond Earth.

In order to make easier for students to achieve a proper level of knowledge and experience in concurrent design, a frame of cooperation has been established between the students from the first year, who are new to concurrent engineering, and second year students, that have gathered a significant level of experience in the previous year. This cooperation enables the comprehensive and resource-effective use of the CDF and ensures the success in the mission design studies.

This cooperation is based on different activities which are conducted in the CDF and that involves concurrent design of space missions working with the available material of own creation. Through this method, collaboration and communications skills are improved and also concurrent design concepts are more easily learnt.

The paper describes the activities involved in this process of cooperation, how they fit in the master's academic program and the results of the method implementation during the academic year 2017/2018. It also includes the working methodology employed in the CDF, developed mainly by students and that is being improved progressively through student generations.

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The Spanish contribution to the 1st ESA Concurrent Engineering Challenge: design of the Moon Explorer and Observer of Water-ice (MEOW) mission

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Abstract

The IDR/UPM Institute (*Instituto Universitario de Microgravedad 'Ignacio da Riva'*) joined the 1st ESA Concurrent Engineering Challenge in September 2017. The aim of this Challenge, organized by the ESA Academy, is to gather around students of different ESA members or associated States to design a mission in the ESA CDF. Besides, three more groups of students from different institutions, *Universidad Politécnica de Madrid* (Spain), *Politecnico di Torino* (Italy), and University of Strathclyde (United Kingdom) were invited to participate in the challenge. In this challenge, students had to design a mission proposed by ESA. The goal of this challenge was not a competition but to share information between the different teams, in order to achieve the best results in all cases. *Universidad Politécnica de Madrid*, represented by students and professors from the Master in Space Systems (MUSE), successfully developed a full mission fulfilling the ESA requirements called Moon Explorer and Observer of Water-ice (MEOW). In the present work, the design process of the mission from the educational point of view is presented. Including the students preparation, the challenges encountered, leasons learned and how this experience contributed to improve the IDR/UPM Concurrent Design Facility.

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Overview and Results of the Inaugural ESA Concurrent Engineering Workshop Dedicated to CubeSats and the Subsequent Applications and Implementation for a University CubeSat Design Project

L. Brewster

Carleton University, Ottawa, Canada

CubeSats are growing area of spacecraft design that allows for rapid design and testing of new technology for companies and space agencies, while also acting as a feasible hands-on entrance to satellite design at the University level. This paper serves to highlight two areas that bring together CubeSats and the Concurrent Engineering Design Process:

1. A formal outline and summary of ESA's Inaugural Systems and Concurrent Engineering Workshop dedicated to CubeSats
2. The application and implementation of the Concurrent Design Tool to CuSAT-1, a 3U forest fire detection CubeSat being designed and built at Carleton University

From January 16 to 19, the ESA Academy held hosted the Inaugural Systems and Concurrent Engineering Workshop dedicated to CubeSats. Held at the Academy Training & Learning Centre, situated within the ground of the Redu Ground Station in Belgium, the workshop brought together 22 students representing their own CubeSat projects from several ESA member states. Unknown to the group, the mission they were tasked with designing had a similar payload and design requirements to that of an already flown CubeSat. The philosophy behind this design choice by the organizers allowed for the students in attendance to directly compare their design results and decisions reached after only 5 design sessions with that of a completed and flown design.

The CuSAT-1 CubeSat from Carleton University in Ottawa, Canada is a 3U CubeSat with a mission objective to use an infrared camera to detect forest fires within the Boreal Forest region of Canada. Each year, a group of 30 undergraduate students works on the project from September through to April as part of their 4th Year Capstone Design Project. The annual turnover of students causes a loss of institutional knowledge, lessons learned, and design information that was not properly documented. The introduction of the Concurrent Design Tool into a project already at the Phase C level of design, serves to bridge the gap in knowledge lose, while also increasing productivity and inter-subsystem communication thanks to a centralized documentation and integration tool. Future application of the Concurrent Design Tool in this project will serve to have smaller groups of students work through the Phase A and B designs of potential new missions in parallel when trying to develop the preliminary design of CuSAT-2.

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ESA Academy 's Concurrent Engineering Workshops

J. Vennekens[1], N. Callens[2], R. Biesbroek[2], A. Cotuna[2], H.P. De Koning[2], J. Huesing[2], M. Scherrmann[2]

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The ESA's Systems and Concurrent Engineering Section in charge of ESA's Concurrent Design Facility (CDF) in ESA-ESTEC (The Netherlands) and the ESA Education Office organise together educational Concurrent Engineering Workshops at the ESA Academy's Training and Learning Centre (TLC) in ESA-ESEC (Belgium). Since the inauguration of the TLC, two and a half years ago, 9 Concurrent Engineering Workshops have taken place in the TLC using the ESA's educational CDF. During these 4 day workshops 22 master and PhD students, from different ESA Member and Associate States and studying in various universities, receive an introduction to the Concurrent Engineering method and design together a space mission. 2 System Engineers from the ESA's CDF share their knowledge and experience with the students to guide their design and introduce them to the advantages of Concurrent Engineering. The students are divided into 2-3 person teams responsible for the design of a specific subsystem. Many of the subsystems from an ESA CDF study are being represented during the workshops: configuration, structure, propulsion, attitude and orbit control, communication, thermal, power, optics and sensors and mission analysis. Every 1 or 2 workshops the mission changes to keep up with today's challenges and interests of the space community. This paper will present the different types of workshops, show statistics and feedback from the participating students and the commonalities and differences between a Concurrent Engineering Workshop and an ESA CDF study.

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Introducing the Australian National Concurrent Design Facility – UNSW Canberra's end-to-end mission design tool

J.-C. Meyer, *D. Griffin*

UNSW Canberra, Canberra, Australia

1. Introduction

Australian space activity has received attention recently with the announcement of the intention to create the Australian space agency. This will open the door for Australia as a nation to conduct bi-lateral satellite missions in the future. Existing and coming mission opportunities require quick and detailed feasibility design iterations making it a perfect environment for the use of concurrent engineering. For this purpose, the space group at University of New South Wales (UNSW) Canberra has recently completed setup of the Australian National Concurrent Design Facility (ANCDF). The ANCDF's primary use case is to study complete, end-to-end space missions with a focus on fulfilling customer needs and providing a viable implementation plan beyond technical feasibility, but it also serves as a research object and education tool.

2. Background of Australian space sector

Today, Australian satellite users are governmental, defence and institutional entities. They create a range of opportunities for satellite manufacturers and mission design teams. The Australian space agency will likely increase these further. The large number of opportunities require a satellite manufacturer to quickly assess a satellite mission and realistically plan its implementation. Without an existing framework of formal design standards, communication between customer and mission design team is of highest importance. These aspects have been the driving design criteria for the ANCDF.

3. Concept for the ANCDF

Broken down into the following principles, the above criteria govern the implementation of the ANCDF:

- ANCDF is a modern, high-tech, working environment to design complex satellite missions
- Working in the ANCDF means doing engineering (and less documentation)
  - But everything done during a CDF study is documented
- Communication among participants is easy and intuitive
- ANCDF results will be used as a starting point for and throughout mission implementation
- ANCDF is inter-operable with other CDFs and usable for external customers

The result is a 16-work-station main facility plus a separate area for splinter meetings.

3.1. Heritage from European concurrent engineering

ANCDF is based on first-hand experience and lessons -learnt in concurrent design facilities at CNES, DLR, ESA ESTEC, OHB System and RAL Space. The data model used is the CNES' IDM-CIC with enhancements for ANCDF-specific requirements. The process for CDF studies is derived from the way DLR, ESA, OHB System and RAL Space are conducting them, but adaptable for project-specific needs.

3.2. Focal points for ANCDF

One major focus of the ANCDF is the inclusion of development schedule and cost estimation into the design process. This requires an adaptation of the data model and the creation of a domain specific tool for the programmatics expert to be able to collaborate at the same speed as the engineering domains.

While being primarily an operational asset, the ANCDF is also designed to be used in education and as a research object. Research will, on the one side, be based on UNSW Canberra competency including e.g. capability modelling and multi-disciplinary design optimisation. On the other hand, the ANCDF is intended to be used for psychology or sociology research in behavioural studies.

For educational purposes, space systems engineering students at UNSW Canberra will have the chance to learn complex systems interactions hands-on and conduct a final-year project within the ANCDF.

4. Status and outlook

Initial setup of the ANCDF has been completed in April 2018. First studies are planned to be run in the ANCDF in the following months. At the same time, it is planned to further extend the ANCDF's capabilities operationally as well as through the research highlighted above.

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DAY 3

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 7 – Concurrent Engineering – Status & Plans

10:55 Review on Concurrent Design practice in the space sector
D. Knoll, *C. Fortin, A. Golkar*
Skolkovo Institute of Science and Technology, Moscow, Russian Federation

11:15 You work with me the way you talk to me – Team dynamics and team building exercise
A.Cotuna
European Space Agency, Noordwijk, The Netherlands

11:35 The devil is in the details: lessons learned from operations for Phase 0 studies
X. Collaud
European Space Agency, Noordwijk, The Netherlands

11:55 Considerations and first steps towards the implementation of Concurrent Engineering in later project phases
A. Martelo, *S. S. Jahnke; O. Romberg*
Deutsches Zentrum für Luft- und Raumfahrt e.V., Institute of Space Systems, Bremen, Germany

Review on Concurrent Design practice in the space sector

D. Knoll, *C. Fortin, A. Golkar*

Skolkovo Institute of Science and Technology, Moscow, Russian Federation

1. Abstract

Over the last decades the concurrent design approach got widely adopted by organizations dealing with feasibility studies of space missions. It has shown to be an effective method to evaluate new space missions as well as to verify given proposals in a time efficient manner. Common to the various implementations of the concurrent engineering paradigm into conceptual design studies are: a multidisciplinary team, a tool for managing a shared system model, a structured process for collaboration, and an environment for the team to get together for concentrated face-to-face work sessions. Besides theses commonalities, different organizations have developed different practices.

The goal of our work is to analyse the differences in people management, tools, processes and facilities across many organizations using this type of concurrent design. Our analysis is primarily based on data collected through a survey along the four topics: 1) people and team, 2) tools and shared model, 3) process, 4) infrastructure and facility. Most of the questions can be evaluated quantitatively to allow a clear characterization of the state-of-the-art. Moreover, we capture current challenges and future trends for each of the four topics. The survey is conducted among subject matter experts involved in various roles in this type of concurrent design.

We explain the different applications of concurrent design approach by their organizational context and the specific purpose the approach is used for. This review gives a broad insight into the practice of concurrent design in the space sector. Finally, we point out topics most relevant for future research.

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You work with me the way you talk to me – Team dynamics and team building exercise

A.Cotuna

European Space Agency, Noordwijk, The Netherlands

1. Introduction

How you ever asked yourself why some teams perform and interact better than others? What makes them different, what motivates them in carrying out their work and overcome critical issues?

In the frame of performing feasibility studies in the Concurrent Design Facility (CDF) at ESA/ESTEC team dynamics is fundamental. CDF activities are conducted in sessions: plenary meetings in which representatives of all space engineering domains participate, from the early phases (requirement analysis) to the end of the design (costing). The decisions regarding the design of a space mission are collectively assessed with the team is being led by a Team Leader, a System Engineer and a System Assistant.

The aim of the paper is to harness the power of language in order to motivate a team working together to achieve a common goal in the CDF, to get to the core of complex issues quickly and to communicate effectively. The presentation targets understanding different individual personality types and introducing the perceptual position concept as a team building exercise demo. Having the flexibility to move between perceptual positions is an incredibly useful skill and can open up the way an individual views and understands any situation, problem, interaction, process or exchange of information.

2. References

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The devil is in the details: lessons learned from operations for Phase 0 studies

X. Collaud

European Space Agency, Noordwijk, The Netherlands

1. Introduction

The operation phase of a mission puts years of planning and design on the grill of reality. Regardless of the quality of the preparation, the operators are required to maximise mission return with a hardware architecture that cannot be altered. The size of a subsystem, the redundancy scheme, or even the way the spacecraft needs to be interacted with will rhythm the daily work of the operators throughout the mission lifetime.

Under the assumption that an optimised system will have more difficulty to adapt to change, the infusion of lessons learned in the early phases should permit to adapt design decision towards a more robust design that would dramatically increase the overall mission chance of success.

2. Objective

This paper aims to propose ways of identify and systematize the return of lessons learned that can add value to the overall mission. As indicated in reference [1], there exist knowledge management procedures within a specialty. The difficulty resides in translating those specific lessons learned to other domains, that have different priorities and whose use of the knowledge may differ from the one intended by the initiator of the data.

It is about underlying the work that can be done in the CDF that would allow to better identify the critical aspects of the mission and address them accordingly.

3. Covered topics

The analysis covers the following points:

- Knowledge management methods
    - Lessons learned from operations
    - Use of databases in the concurrent design facility
- Interfacing
    - Identification of relevant information
    - Pipeline of lessons learned to the early phases databases
    - Introduction of new data into the feasibility analysis

The lessons learned will be assessed in order to bring into relief the added value of a concurrent review with the aim aptly steer the design decisions in order to facilitate the development of the latter phases following a CDF study.

4. References

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Considerations and first steps towards the implementation of Concurrent Engineering in later project phases

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The benefits of Concurrent Engineering (CE) in early space project phases (0/A) have been demonstrated for decades. Many organizations have developed their own processes and tools, with different objectives and levels of integration into their product design cycles, and managed to execute studies in a systematic and efficient way. All of this, however, has not yet been made possible for later phases (B/C/D), of a space technology project.

For CE to be successfully applied in later phases a significant number of obstacles must be overcome, e.g. the high level of complexity of the systems involved, the distribution of industrial partners, or the increasingly large sizes of the teams involved. New tools need to be developed, new work processes will have to be established, and new ways of working will need to be enacted in organizations before CE can support these later activities. The CE team at DLR is focusing at present on the development of an internal process that could integrate the use of CE in combination with the application of Collaborative Engineering into phase B.

A generic process, can only be considered useful to a limited degree if implemented as originally defined. Any such process needs to be adapted to the specific work environment where it is to be executed and, therefore, when contemplating the development and application of a new work process in an organization, a number of different aspects need to be analyzed. The particular characteristics of the organization will affect the process, but also need to adapt to the new process. The methodology the process is aiming to follow will also impact its definition. The tools (i.e. software) that are used or need to be developed will impose its own restrictions to the process, and be influenced by it. These aspects and any number of other project traits will impact the process, and be affected by it.

As part of DLR’s current efforts to develop a working process for the use of CE in Phase B, an analysis of the factors that may influence the development of such a process has been undertaken. The paper will present this analysis, identifying the issues that need to be considered, as well as introducing the specific resulting CE process at DLR.

One concrete first result for this proposed process is the identification of several CE benefitting activity types which shall be organized in a generic sequence from Phase 0 to end of Phase B. This paper presents the defined activity prototypes and a generic overall sequence flow of those activities. Finally, one possible specific implementation for an example project is sketched for clarification and comparison with a classical work approach.

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DAY 3

8th International Systems & Concurrent Engineering for Space Applications Conference (SECESA 2018)

at the Technology & Innovation Centre (TIC), in Glasgow, on **26-28 September 2018**

Session 8 – Future Trends in Engineering Design

13:55 Improved Collaborative Optimization for Multidisciplinary Design Optimization Problems
S. Zhang[1], E. Minisci[2], *M Liu*[1], *Y Huang*[1] *and A Riccardi*[2]
[1]*Northwestern Polytechnical University, Xi'an, China,* [2]*University of Strathclyde, Glasgow, United Kingdom*

14:15 A Microservice-Based Multi-Cluster Computation Platform for Space Mission Design
Y. Song[1], *H. Xinxing*[1], *S. Yang*[1], *L. Zhu*[1], *Z. Yang*[2], *L. Deng*[2]
[1]*Software School, Beihang University, Beijing, China,*
[2]*National Space Science Center, Chinese Academy of Sciences, Beijing, China*

14:35 Robust Design Optimisation of Dynamical Space Systems
G. Filippi[1], *M. Vasile*[1], *Z. Korondi*[2,3], M. Marchi[3], *C. Poloni*[2,3]
[1]*University of Strathclyde, Glasgow, United Kingdom,* [2]*University of Trieste, Trieste, Italy,*
[3]*ESTECO SpA, Trieste, Italy*

14:55 Phased mission system reliability with imprecise mission timing

D. Krpelik[1,2], *X. Huang*[3], *L.J.M Aslett*[1], *F.P.A. Coolen*[1]

[1]*Department of Mathematical Sciences, Durham University, Durham, United Kingdom,* [2]*Department of Applied Mathematics, VŠB - Technical University of Ostrava, Ostrava-Poruba, Czech Republic,* [3]*School of Mechanical Engineering and Automation, Northeastern University, Shenyang City, China*

15:15 Sensitivity Analysis Tool for Complex Space Missions Using Machine Learning

Z. Yuzhu, *P. Xiaodong, Y. Zhen*
National Space Science Center, Chinese Academy of Sciences, Beijing, China

Improved Collaborative Optimization for Multidisciplinary Design Optimization Problems

S. Zhang[1], E. Minisci[2], M Liu[1], Y Huang[1] and A Riccardi[2]

[1]Northwestern Polytechnical University, Xi'an, China
[2]University of Strathclyde, Glasgow, United Kingdom

1. Introduction

In this contribution, an improved version of the standard collaborative optimization (CO), a distributed optimization method for multidisciplinary design optimization (MDO) [1], is proposed. The key idea in Improved Collaborative Optimization (ICO) is to consider the global objective in each subspace optimization problem with an additional interaction channel for coupling variables, while maintaining an easy coordination of design variables for system level problem. The improved collaborative optimization has two main advantages: 1) ICO enhances the subspace design authority; 2) ICO makes it possible for direct information interaction among subspaces. See Figure 1 for the frame work of ICO.

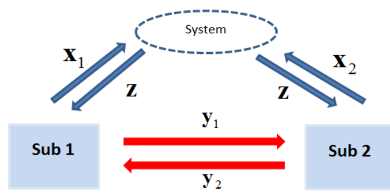

Figure 1: ICO with two disciplines

2. The method of ICO

The system level is an unconstrained minimization problem with a memory of coupling variables:

$$\{\min \ J_{\text{sys}} = \sum (z - x_s^*)^2, sto(y)\}$$
$$s.t. \quad \text{No constraints}$$

The subspace level is an independent optimization problem:

$$\begin{aligned} \min \quad & J_i = F(x_s) + \lambda_c \sum (x_s - z)^2 \\ \text{s.t.} \quad & g_{\mathbf{i}}(x_s, x_i, y_i, y_j) \geq 0 \\ & y_i = D_i(x_s, x_i, y_j) \quad i, j = 1, \ldots, n \quad i \neq j \end{aligned}$$

3. Solution process and application

In the first step, the initial system level targets for shared variables and a set of initial coupling variables are sent to each subspace. The subspace treats the targets and necessary coupling variables as parameters, allowing it to solve its optimization problem without requiring other subspaces' constraints or analysis information. The subspace returns target responses and the output of discipline analysis (coupling variable/state variable) to the system level. In the second step, the system level obtains the average of the target responses returned from the subspaces. Besides, it stores the coupling variables provided by the subspaces directly. The targets and coupling variables are then updated. The process is repeated until compatibility is realized. The results on analytic and engineering test cases show that ICO performs better than CO in terms of computational efficiency.

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A Microservice-Based Multi-Cluster Computation Platform for Space Mission Design

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5. Introduction

Large scale simulation is one of the dominant features in space mission design, which involves complex algorithms as well as calculation structures from a wide range of related research fields. In this work, we designed a high-performance integrated computation platform, which enables multiple client applications to invoke calculation formally and compactly in order to serve the space mission design. Based on the ideas of microservice and Logic-Interface orchestration method (LIOM), the proposed platform could integrate modules and/or algorithms from existing deployed clusters. Definition of calculation flow and dependency analysis method are used for performance optimization by achieving two-level parallel computing. In the production environment, the proposed computation platform has been applied in multiple space mission projects, such as Dark Matter Particle Explorer (DAMPE, also known as 'Wukong' in China), Quantum Teleportation Satellite (known as 'Mozi' in China) and Insight-HXMT (Hard X-ray Modulation Telescope)[1-4], which presents isolation between space mission design logic and various calculation implementations, featuring both efficiency and easy-to-use experience.

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Robust Design Optimisation of Dynamical Space Systems

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1. Abstract

In this paper we present a novel approach to the optimisation of complex systems affected by epistemic uncertainty when system and uncertainty evolve dynamically with time. Epistemic uncertainty is due to a lack of knowledge or to incomplete information. This type of uncertainty is typical in early design phases, when multiple experts are providing different opinions, models are low fidelity or in the case of poor quality and incomplete data.

Evidence Theory provides a valid mathematical tool to model this type of uncertainty [1,2,3] though it is computationally expensive and difficult to handle. In this paper we propose a new modelling approach that uses Evidence Theory to capture epistemic uncertainty and provide an efficient calculation of the quantities of interest. The new approach is called "Evidence Network Model" (ENM) and it was introduced in [4] and extended in [5] to model engineering systems that can be decomposed in a number of subsystems or functions. ENMs are undirected and connected graphs where each node is a sub-system and each link an information pathway. In this work, ENMs are extended to include time dependent uncertainty and a time varying performance criterion.

In particular, in this work we consider the case in which the behaviour of some components of the system is affected by time during the operational life (failure rate, performance degradation, function degradation, etc.). The goal is to obtain a solution that is robust with respect to performance variability and is resilient against possible partial failures of one or more components.

The computational method proposed in this paper exploits the nature of ENM and decomposes the problem into subproblems of smaller complexity, under suitable assumptions. The overall quantification of robustness and resilience is then derived from an assembly process of all the subproblems. This decomposition method, called h-decomposition, reduces the computational cost and makes the quantification of uncertainty in complex systems affordable for a range of real-world applications.

A simple example demonstrates that ENMs are a valid tool for the preliminary design of complex space systems that are affected by time varying epistemic uncertainty. The method is here applied to a resource allocation problem where the goal is to optimally position components within a spacecraft [6]. The objective function is the minimisation of the moment of inertia relative to the vertical axis and the way the subsystems and components are allocated influences the centre of gravity of the whole system. The mass and size of each component is affected by uncertainty in system design parameters and system degradation. A failure rate - function of time and affected by epistemic uncertainty- is used to quantify the performance degradation of the power system. The failure rate is then used to modify the number and type of cells of the solar panels and of the batteries. The variation of these parameters induces a change of the mass and size of the component and as a result the barycentre and moment of inertia of the whole system.

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Phased mission system reliability with imprecise mission timing

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1. Introduction

A Phased Mission System (PMS) performs multiple functions or tasks in sequence, where each part of the mission may involve different components in the system. For example, a space mission may involve launch, orbital and re-entry phases, each of which involves very different subsystems, components and stresses on the system.

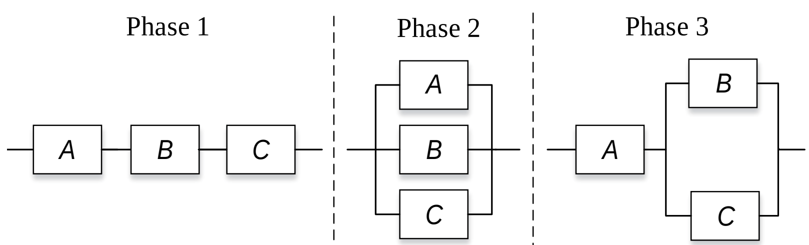

Figure 1: Toy example of how a reliability block diagram may vary across mission phases.

As such, designing highly reliable PMSs can be challenging since every phase must achieve a high level of reliability. This calls for an effective reliability assessment that accounts for as many uncertainties in the system as possible.

2. Reliability assessment

There has been work on reliability and component importance assessment for PMSs [1]. In that work, the survival signature [2] was generalised to the PMS setting, enabling the natural separation of system structure and component lifetimes afforded by the survival signature to be extended to this more complex setting. As such, uncertainty in component reliability could be assessed across changing system functions and design.

A limitation of the analysis in [1] is that the duration of all phases in the mission is assumed to be precisely known apriori. Therefore, we contribute a crucial extension to [1], whereby uncertainty in the duration of mission phases is robustly accounted for within the framework of imprecise probability. This enables full reliability assessment of PMSs under the more realistic constraint that phase duration is highly uncertain: as such, we only require upper and lower bounds on phase duration, with both component and duration uncertainty then propagated through the analysis to give reliability bounds for any chosen mission time of interest, or bounds on the whole survival curve of the PMS.

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Sensitivity Analysis Tool for Complex Space Missions Using Machine Learning

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1. Introduction

In recent years, more and higher requirements are exerted upon space science satellite design and development as the number of these mission increases, especially space mission with complex system designs. These complex space missions contain a large number of various uncertainties, and their forms of expression are diverse, including randomness, ambiguity, imperfections and so on; these uncertain factors, mainly due to the system composition and its operating environment where contains a large number of randomness, ambiguity, subjective decision-making. In addition, there are complex coupling relationships between these uncertainties, and the simulation of uncertainties is complex.

In the whole life cycle of a space mission, especially in the process of demonstration and concept design, global sensitivity analysis of these uncertainties attracted a large amount of attention by domestic and foreign space agencies and related fields. In order to determine the influence of the uncertain factors in a space mission, many global sensitivity analysis methods are proposed. The limitations of the proposed methods are: 1) requires a function which is not realistic for a complex system; 2) curse of dimensionality;3) inaccurate for nonlinear systems, and so on. Therefore, we proposed a global sensitivity computation method based on machine learning and Monte Carlo simulation and tried to address the above issues.

This method takes related uncertainties into account, and will provide the theoretical basis for global sensitivity analysis for complex system. It also provides a global sensitivity analysis model for space missions which could support further system optimization. In addition, this proposed global sensitivity analysis tool is supplementary to the Concurrent Design and Simulation Platform at National Space Science Center, Chinese Academy of Sciences (NSSC), and it will benefit to make full use of resources and save cost during the iterative process of concept design.

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