How to Advance Interdisciplinary Model Based Engineering of Space Systems?

Hans Peter de Koning (ESA)

SESP, 28-30 March 2017, ESA/ESTEC

ring Information Between Disciplines

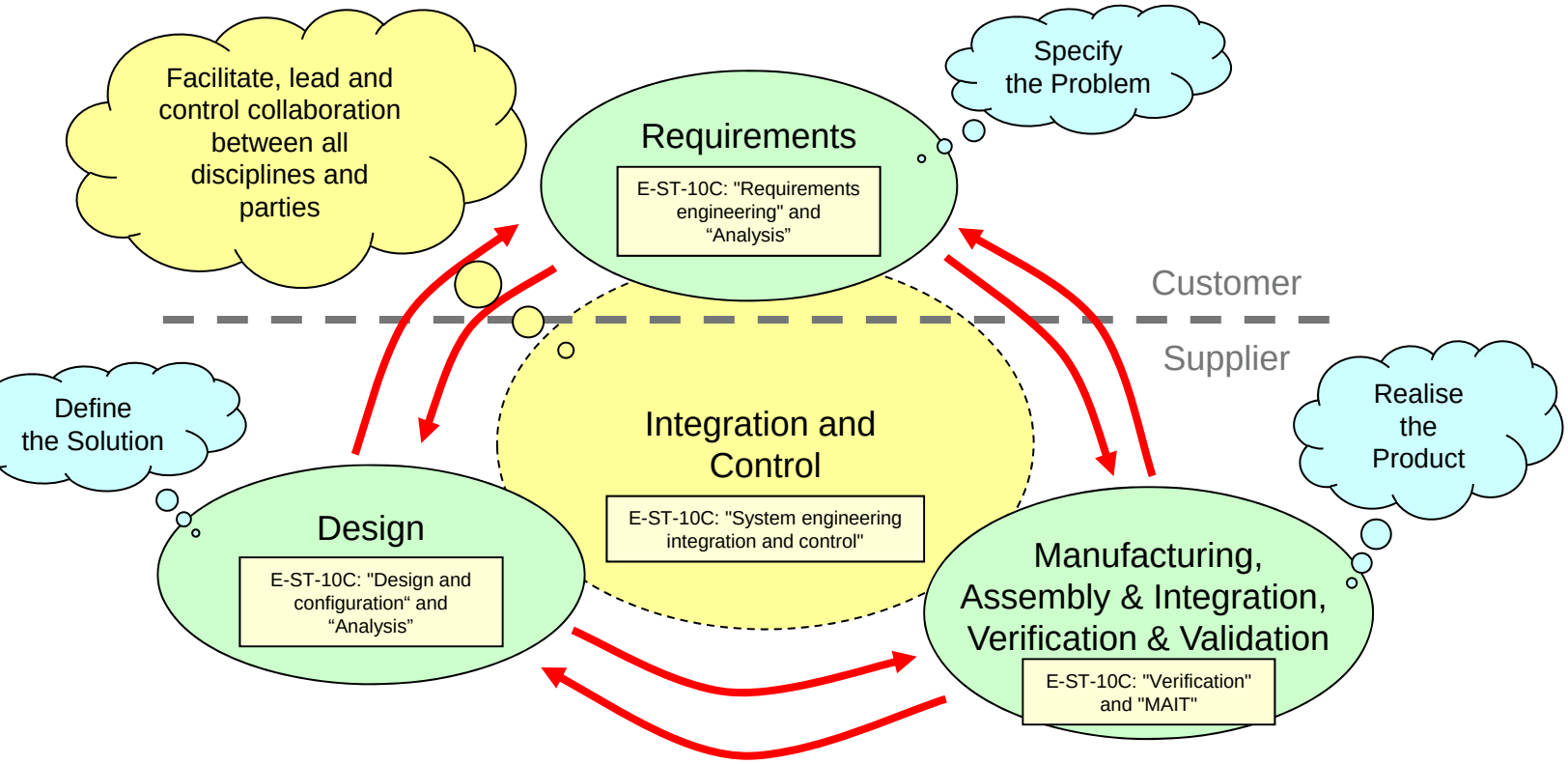
ng the right version
the right information
the right team member
the right time …

ring consistent, complete, navigable, reviewable information
while making a deadline

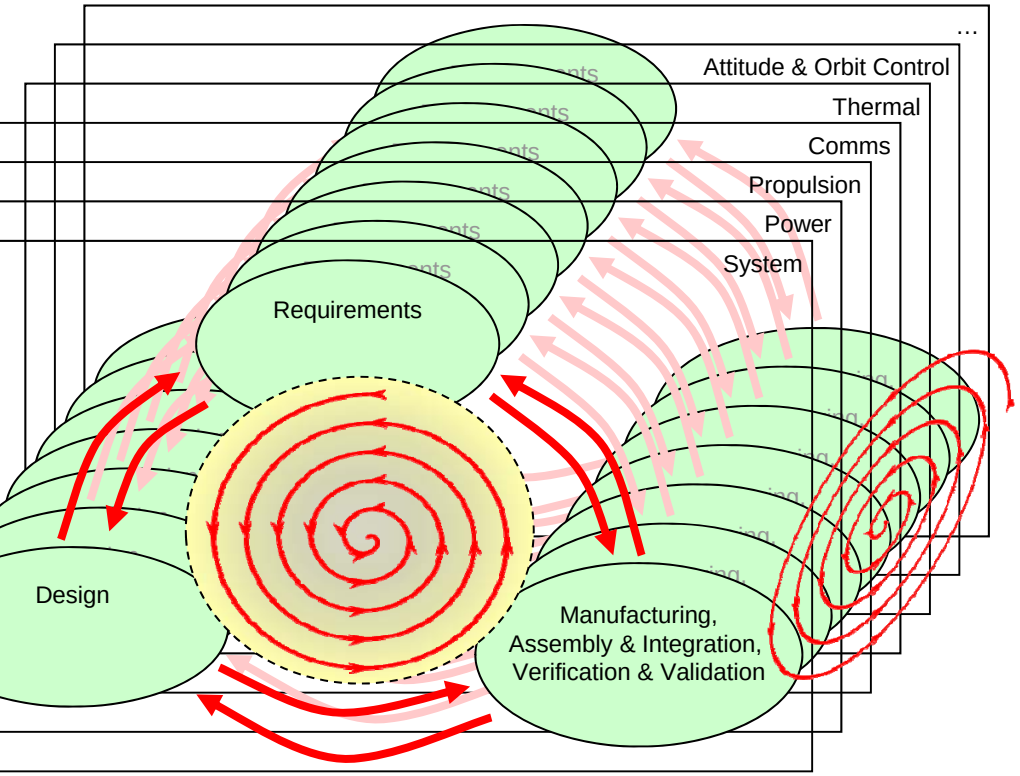
ajor challenges in all our projects

gital engineering / model based approaches promise substantial
provements … but do not fall from the sky for free

tem Engineering according to ECSS-E-ST-10C

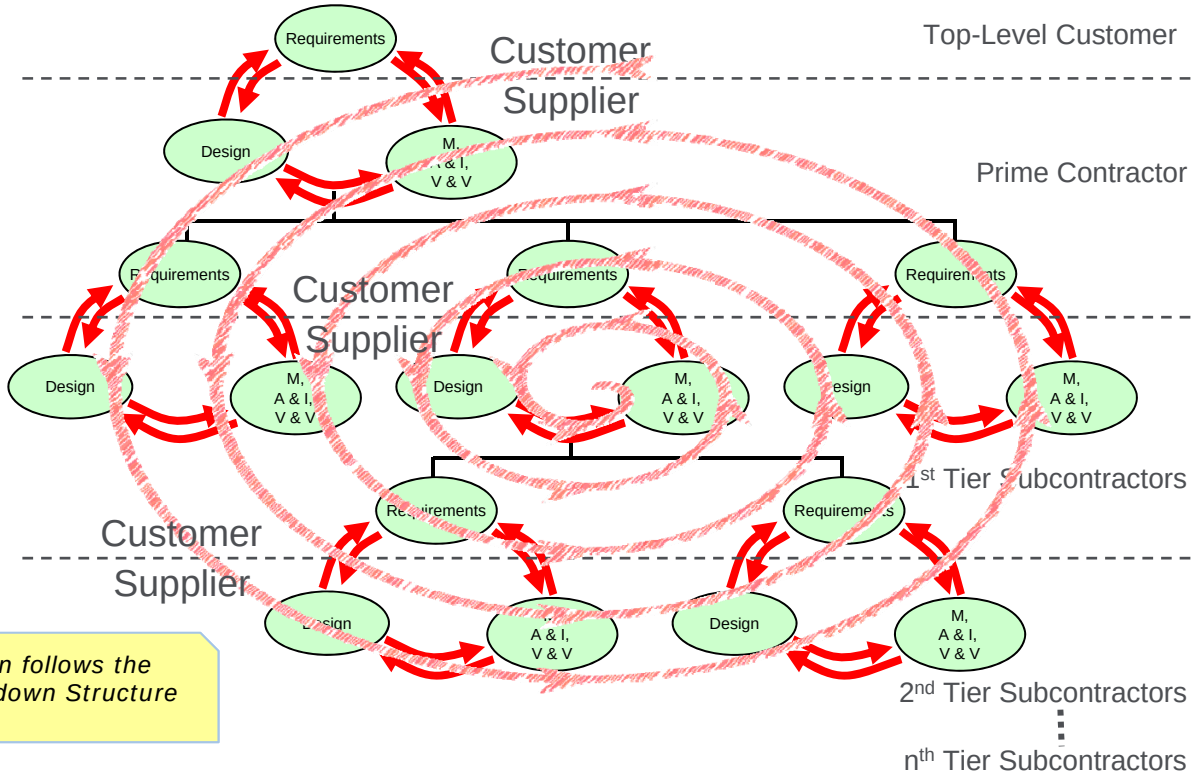


S-E-ST-10C: Iterative “Integration and Control”



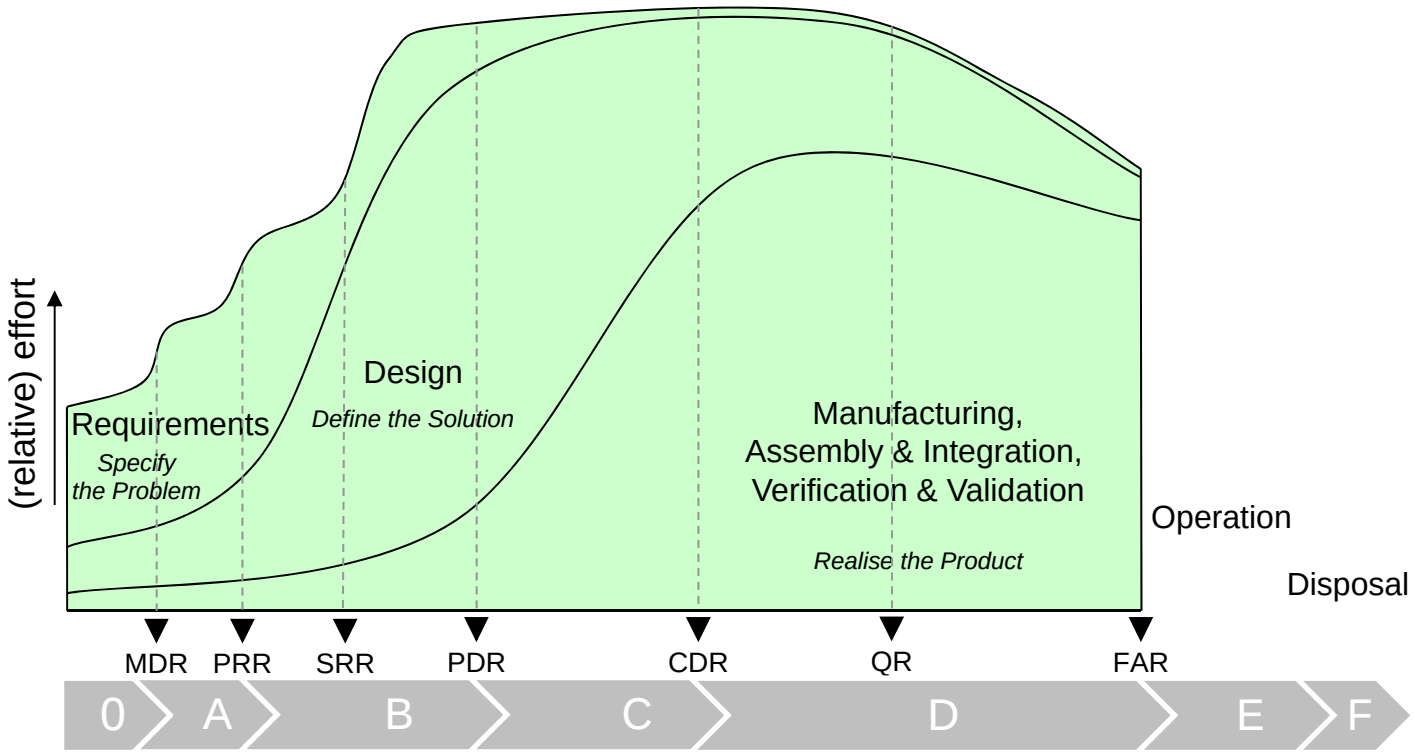
- Integration and Control
  - Concurrent in early phases
- Iterate between Requirements, Design, and MAIV&V
- Iterate across Disciplines

ECSS-E-ST-10C: “Integration and Control” Across the Customer-Supplier Chain

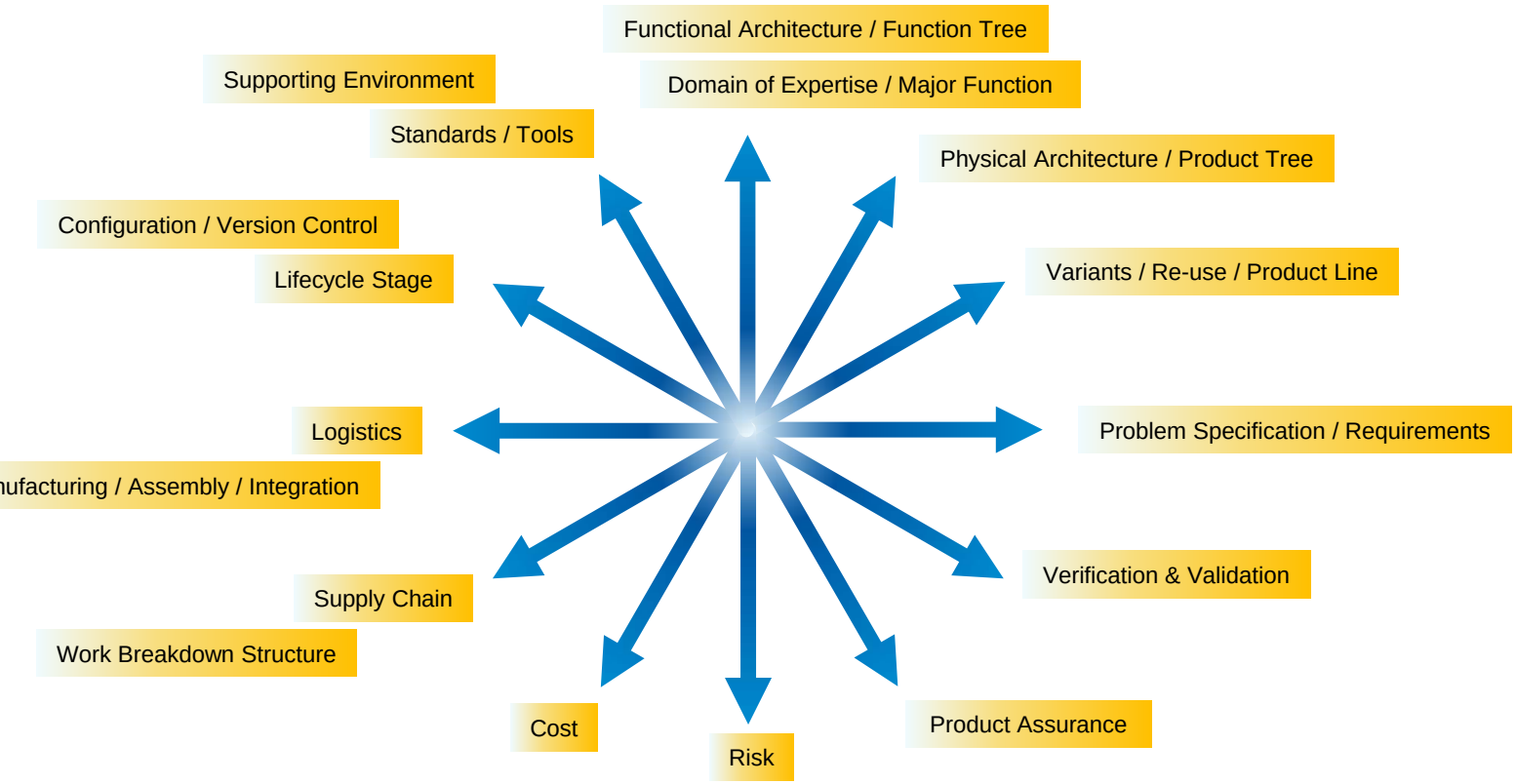


The Customer-Supplier Chain follows the Product Tree or Work Breakdown Structure or a combination thereof

S-E-ST-10C: “Integration and Control”
rt along the System Life-Cycle



uge Information Management / Knowledge esentation Exercise ... across many dimensions

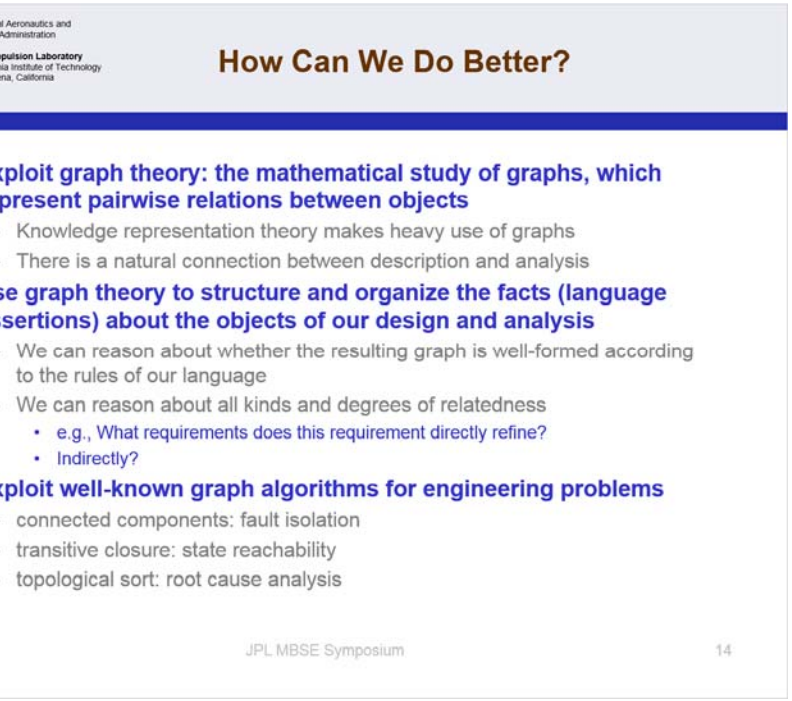


Need Rigorous System Engineering

ry inspiring talk at NASA/JPL
BSE Symposium – Jan 2017 –
Steven Jenkins (JPL)
Systems Engineering Really
gineering?"

etorical, rather: "How do we
sure that systems engineering
ally is engineering?"

tes from Steven Jenkins



l Aeronautics and Administration
pulsion Laboratory
ia Institute of Technology
na, California

How Can We Do Better?

xploit graph theory: the mathematical study of graphs, which present pairwise relations between objects

- Knowledge representation theory makes heavy use of graphs
- There is a natural connection between description and analysis

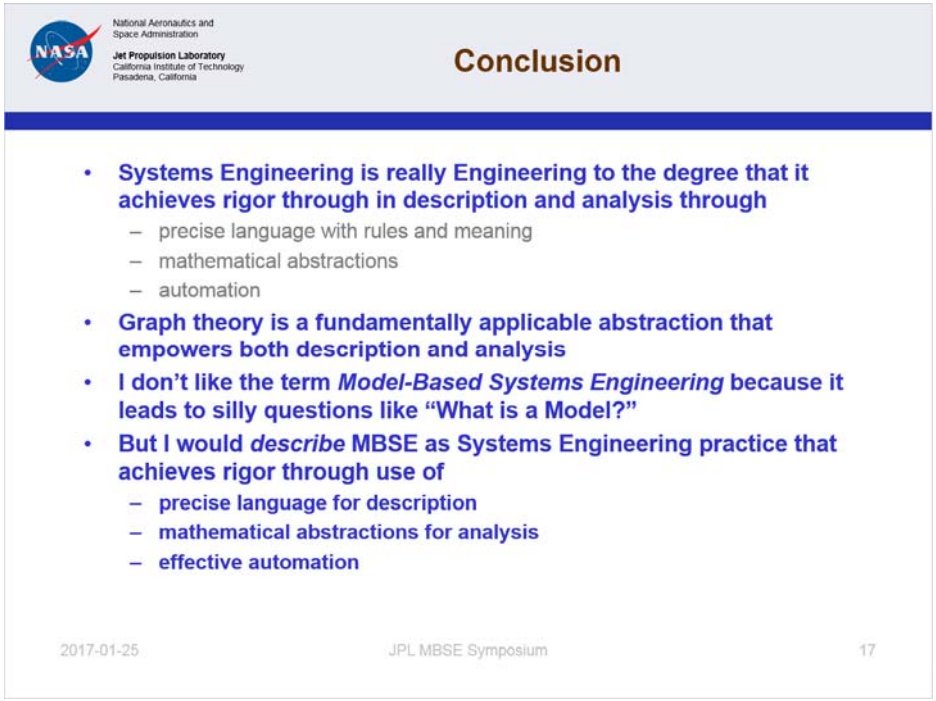
se graph theory to structure and organize the facts (language ssertions) about the objects of our design and analysis

- We can reason about whether the resulting graph is well-formed according to the rules of our language
- We can reason about all kinds and degrees of relatedness
  - e.g., What requirements does this requirement directly refine?
  - Indirectly?

xploit well-known graph algorithms for engineering problems

- connected components: fault isolation
- transitive closure: state reachability
- topological sort: root cause analysis

JPL MBSE Symposium 14



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

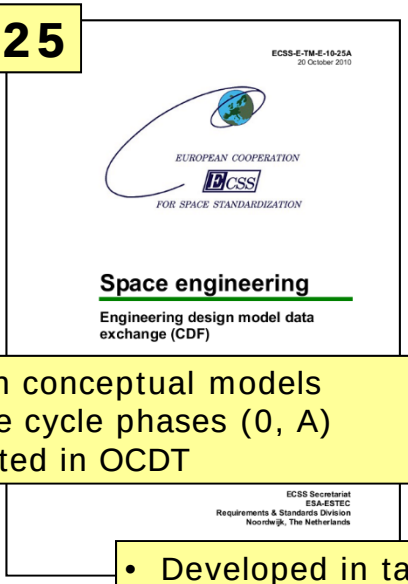
Conclusion

- **Systems Engineering is really Engineering to the degree that it achieves rigor through in description and analysis through**
  - precise language with rules and meaning
  - mathematical abstractions
  - automation
- **Graph theory is a fundamentally applicable abstraction that empowers both description and analysis**
- **I don't like the term *Model-Based Systems Engineering* because it leads to silly questions like "What is a Model?"**
- **But I would *describe* MBSE as Systems Engineering practice that achieves rigor through use of**
  - **precise language for description**
  - **mathematical abstractions for analysis**
  - **effective automation**

2017-01-25 JPL MBSE Symposium 17

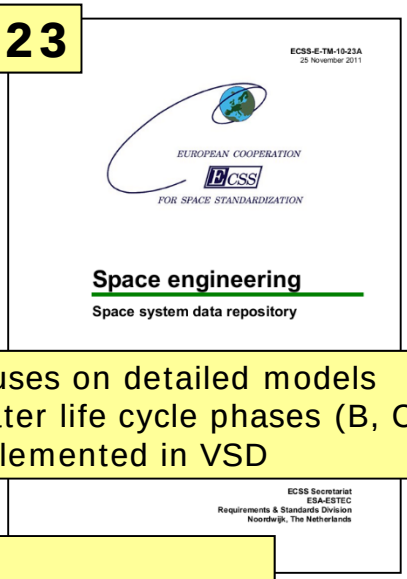
S Semantic Data Models in support of MBSE

E-TM-10-25



- Focuses on conceptual models in early life cycle phases (0, A)
- Implemented in OCDT

E-TM-10-23



- Focuses on detailed models in later life cycle phases (B, C, D, E)
- Implemented in VSD

- Developed in tandem
- Where possible common approach and semantics
- Where possible aligned with OMG SysML
- Plan: Future merge to single real standard
- E-TM-10-25A made available Oct 2010
- E-TM-10-23A made available Nov 2011

M-10-23 & 25 Approach

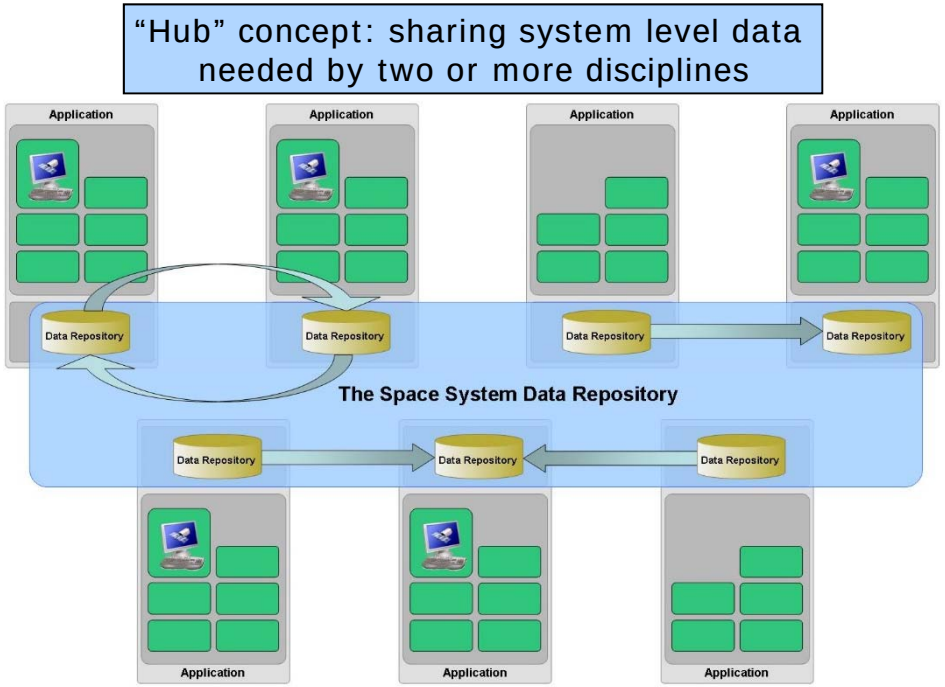
Gs realised early on: in order to ensure long term interoperability must create semantic nceptual data model – i.e. the ontology approach

- At the time (2006-2011) not yet the means nor expertise …
- … Best effort with 'semantic' UML / Ecore models
- Auto-generate implementation technology from conceptual data model – as much as possible

ormation sharing via "Hub": ace System Data Repository

- Federation of data stores with adapters complying to semantic standard model

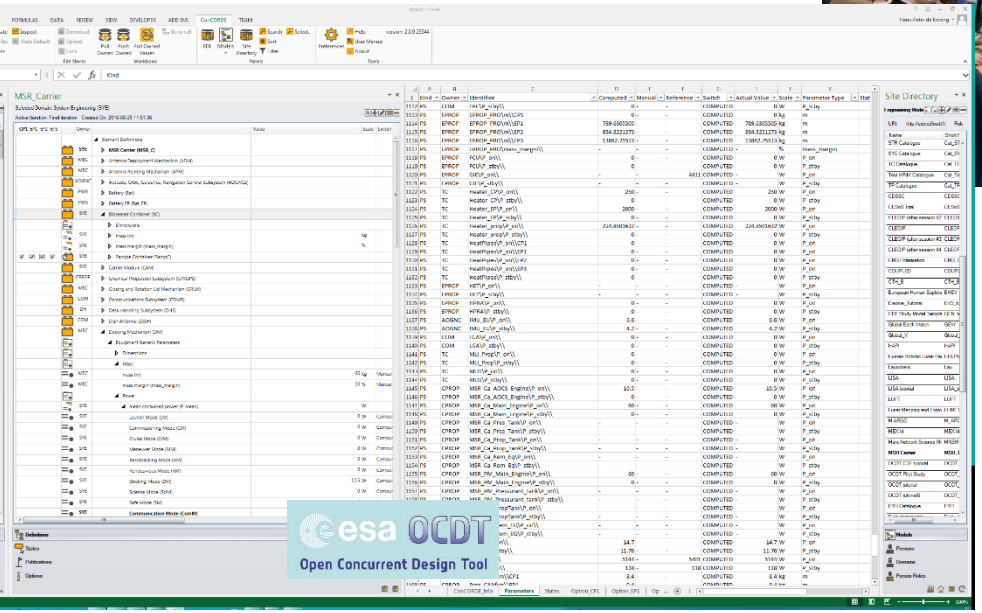
proach reconfirmed in 2014 chnical Harmonisation ystem Data Repository"

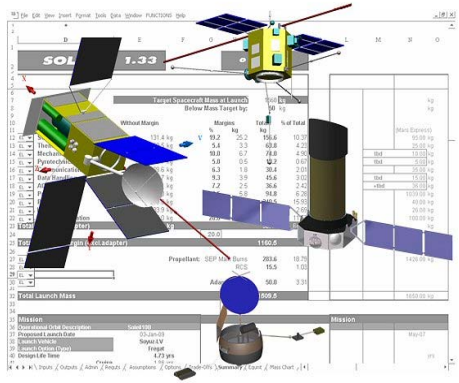


Concurrent Design Facility (CDF)

urrent engineering of conceptual
n of all candidate ESA missions
ling risk, cost, programmatics

20 studies per year





erns implemented in E-TM-10-25 (and OCDT)

wnership / responsibility by Domain of Expertise
- “Domain of Expertise” is generalization of “Discipline”

ambiguous stable object identifiers – UUIDs

paration of “Core Data Concepts” and “Reference Data”
- Core Data Concepts are hard-coded in (generated) software implementation
- Reference Data is loaded at run-time and provides extension mechanism

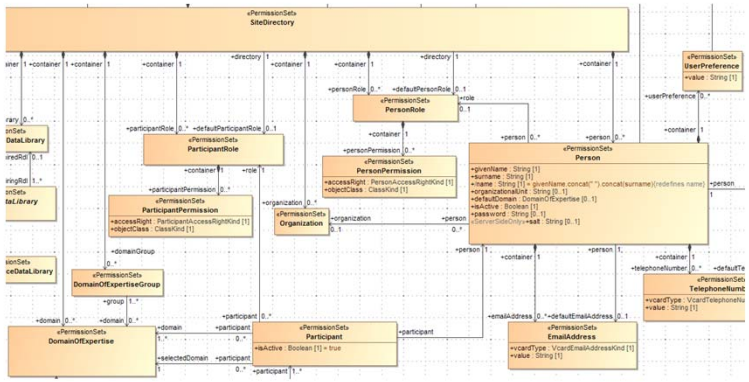
gorous formal model of Quantities, Units, Scales, Physical Dimensions

eb Service with simple HTTP(S) REST API
- Encapsulates persistent data store / hides implementation detail
- Compatible with secure traversal of corporate firewalls

ership / Responsibility by Domain of Expertise

rson represents a user
with **PersonRole** & **PersonPermission** at **SiteDirectory** level

rticipant is a **Person** representing e (or more) **DomainOfExpertise** one **EngineeringModel**
with **ParticipantRole** & **ParticipantPermission** at **EngineeringModel** level



rticipant acts as one **DomainOfExpertise** at any time in a session

ery model **Element** and every **Parameter** in an **EngineeringModel** is owned one **DomainOfExpertise** who is responsible for its definition / value

n-owner **DomainOfExpertise** can take a **Subscription** on **Parameter** to e it as input

mbiguous Stable Object Identifiers – UUIDs

UID version 4 as object id on all classes

- No central id authority needed
- Solid algorithms available in all programming languages
- Allows renaming of human readable identifiers without need for schema migration
- No collisions in 2 years of operation in CDF
- Simplifies primary / foreign keys in persistent and in-memory data stores

ternalIdentifierMap to capture correspondence mapping between TM-10-25 / OCDT UUIDs and identifiers in external models

- Reduces as much as possible the loss of information when performing round trip import / export data transfer between an E-TM-10-25 compliant model and a model in the format of an external tool

aration of “Core Data Concepts” “Reference Data”

ferenceDataLibrary (RDL)

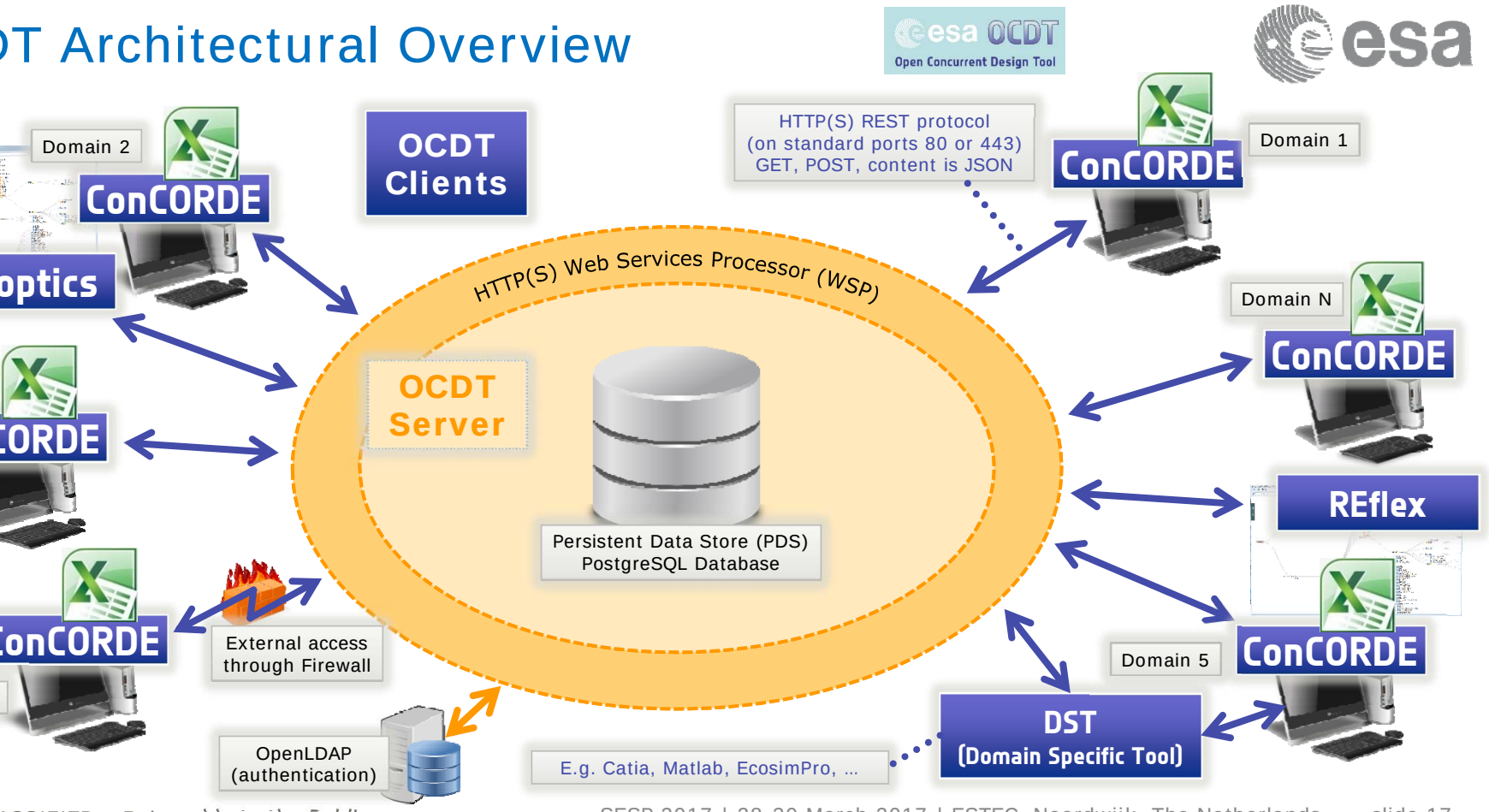
- **ParameterType** definition of **Parameter** type (everything except its value)
  - Comprises **Text**, **Date**, **Time**, **Boolean**, **Enum**, **QuantityKind** scalar subtypes, as well as **CompoundParameterType**
- **Category** for user-defined categorization / filtering of concepts
- **Rule** for user-defined verification rules
- **MeasurementUnit** and **MeasurementScale** to support **QuantityKind**
  - Same concepts as SysML QUDV model library
  - Establishes all info needed for automated unit/scale value conversion
  - Supports ratio, interval, logarithmic, cyclic and ordinal scales
- **Constant** for mathematical, physical, model constants
- **Glossary** of **Term**s
- **ReferenceSource** and **Citation**

neric RDL provided by ESA defines **ParameterType**s most used in space missions

- Including ISO/IEC 80000 quantities, units, scales

ltiple **RDLs** may be chained: e.g. model-specific → family-of-projects → generic

OT Architectural Overview



p Service with simple HTTP(S) REST API

andardized in E-TM-10-25 Annex C

- See https://ocdt.esa.int/projects/ocdt/wiki/ECSS-E-TM-10-25-Annex-C
- HTTP(S) GET and POST on standard ports 80 or 443
- JSON request / response body – flat array of JSON serialized objects
- ACID safe transactions with PostgreSQL database backend
- URI navigation follows top-down composite structure of conceptual data model
- Query parameter *extent=shallow/deep* to get single object or object (sub)graph
- Supports getting delta since given revision number
- Compatible with near-real-time support for 50+ concurrent users and multiple models at 30 seconds synchronization interval for all users

ditional off-line exchange file format in similar JSON files in ZIP archive

CDT implementation on nodejs in TypeScript

ry positive experience – robust, flexible, performant, easy to debug

hain Specific Tool Integrations

ck and Dirty" integrations via Excel worksheets
a v5 bi-directional interface for 3D Configuration in CDF studies
- Basic geometric shapes and coordinate transformations
- Catia computes centre-of-gravity and moments-of-inertia
- Currently alpha version – full operational release expected summer 2017

irectional SysML / UPDM interface (MagicDraw / ESA-AF)
- Alpha version developed in CESoS activity (2014)

Cycle Assessment tool OPERA (in support of CleanSat)
- Expected operational release summer 2017

ab interface by University of Madrid
- Alpha version demonstrated in SECESA 2016

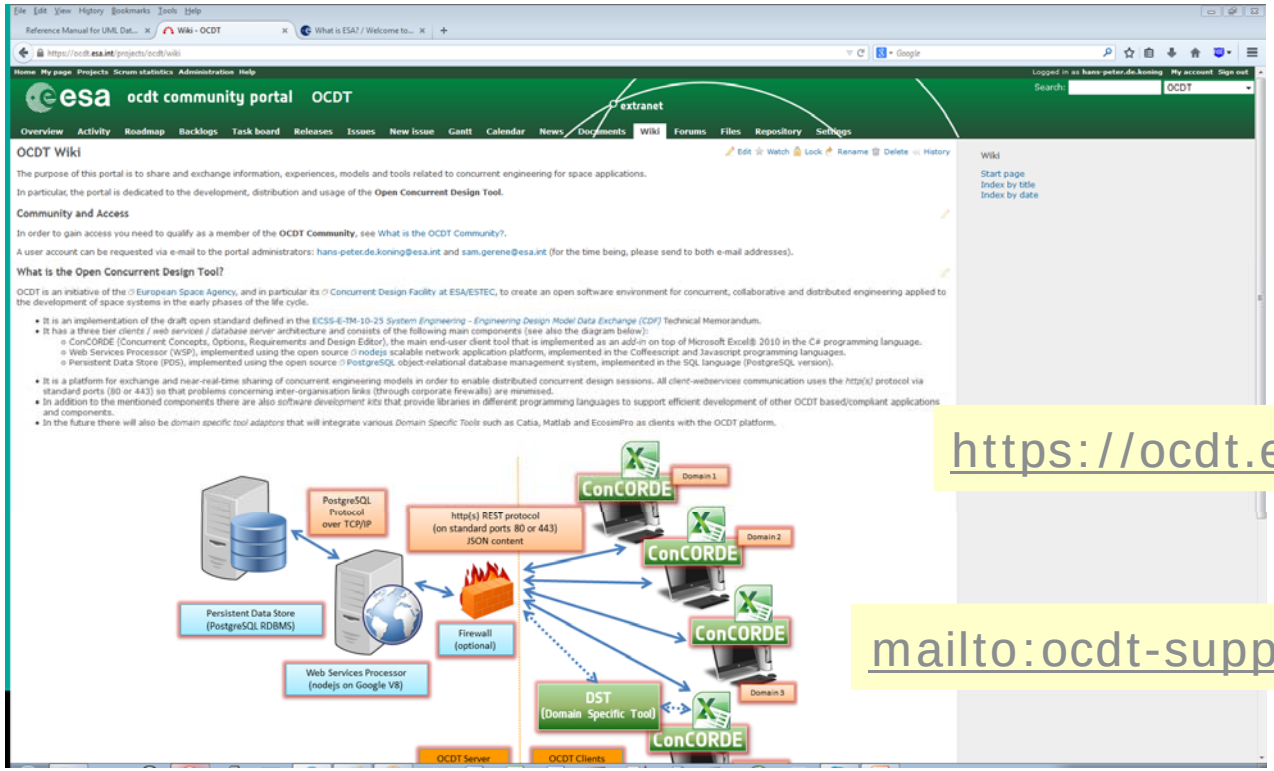
uirements Engineering – DOORS via ReqIF, and SysML (MagicDraw)
- In progress in Flexible Wiki-based Requirements Engineering activity: RE*flex*
- Expected operational release summer 2017

dover to VSD successfully prototyped, connection with e.g. MARVL in future
s for Capella, EcosimPro, Thermal via STEP-TAS, maturing SysML and Matlab interfaces, Ground Segment
ineering …

clusions & Outlook

- periences with E-TM-10-25 / OCDT show that “Multi-Disciplinary Hub” based on semantic nceptual data model starts to work
  - For Phase 0 / A / B type data
  - Feature requests / improvements collected on OCDT Portal Backlog
- od reasons to continue with pragmatic incremental approach
  - Not forgetting long term goals
  - Feed back lessons learned into further ESA, ECSS and OMG SysML v2
- G SysML version 2 looks like taking same approach
  - REST-like services API will become part of the standard
  - Will most probably get much cleaner / ontology like meta-model allowing for Hub capability
  - Major emphasis on usability and reducing the learning curve
  - RPF expected Dec 2017 – Standard and implementation around 2019 / 2020
- ntinue and deepen semantic modelling approaches based on formal logic, semantic web hnology (RDF/OWL/Open Linked Data, FBM) including automated reasoning
- ntinue operations in ESA CDF and with ESA partners in industry and academia

OT Community Portal



https://ocdt.esa.int

mailto:ocdt-support@esa.int