ENG-411
Concurrent Engineering of Space Missions

Source: ESA

Lecture 3 - Subsystems and COMET

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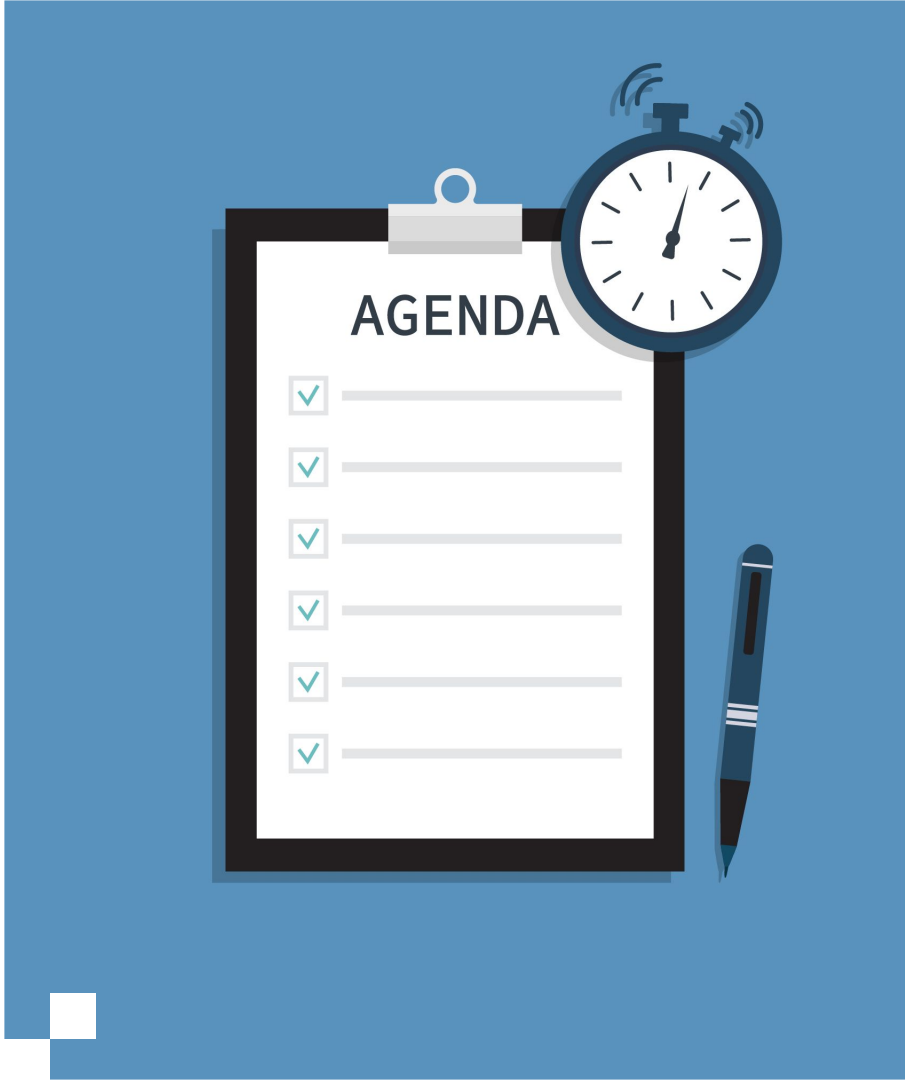
Concurrent Design Facility

Education

Session’s goal

- Subsystems presentation
  - Resources
  - Calculation sheets
- COMET Tutorial
  - Introduction
  - Roles & domains
  - Model
  - Ownership & subscription
  - Three switch mechanism
  - Excel add-in
- Questions?



EPFL Space Center
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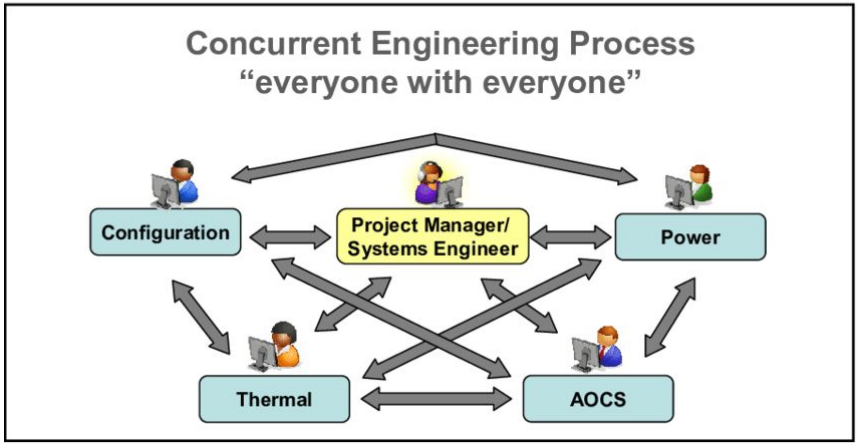
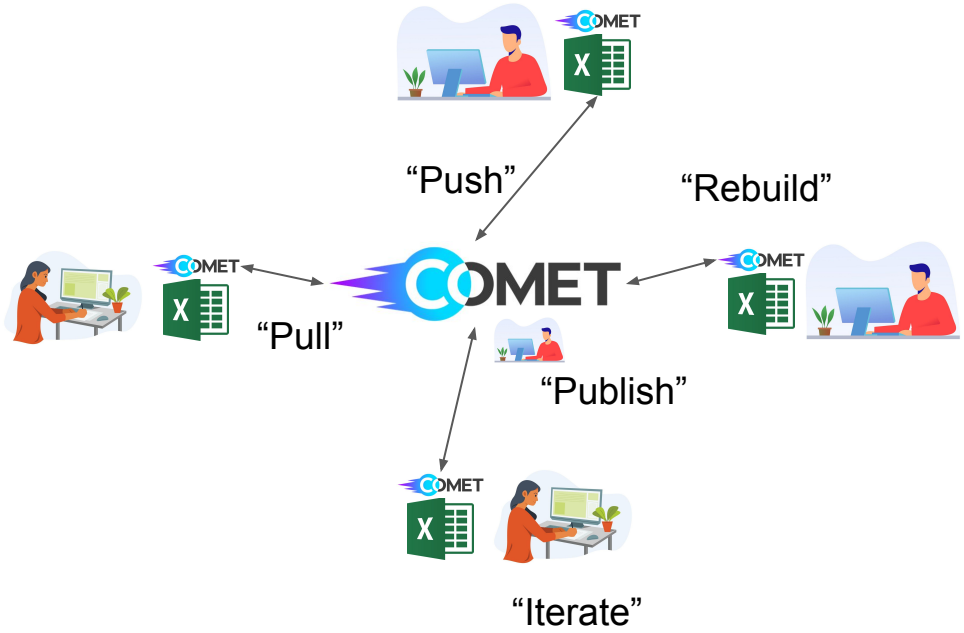
Data exchange

History at ESA:
< 2006: Integrated Design Model (IDM) in MS Excel
< 2022: Open Concurrent Design Tool (OCDT)
→ Now: **COMET** Integrated Modelling Environment (IME)

Others: eg. Valispace, and many more



Source: Volker Maiwald et al. (2010) "DLR Feasibility Study SolmeX - CE Study Report"



Subsystems

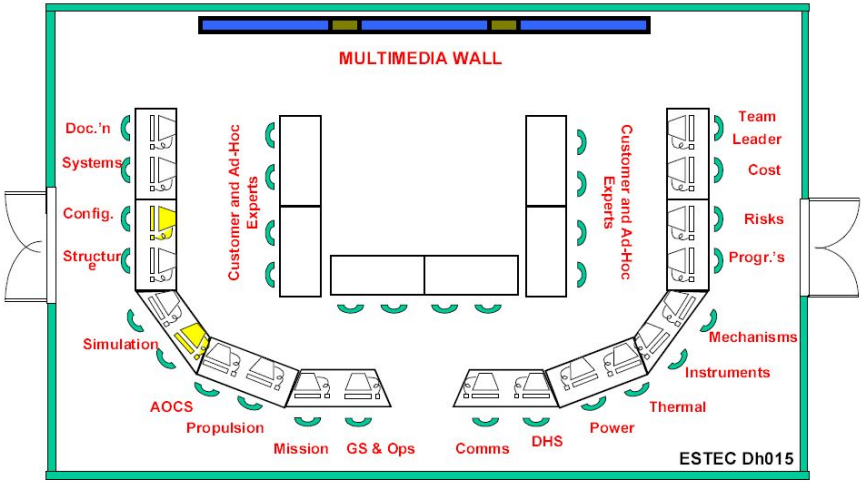
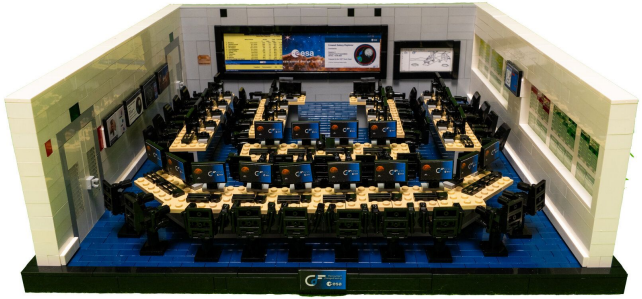


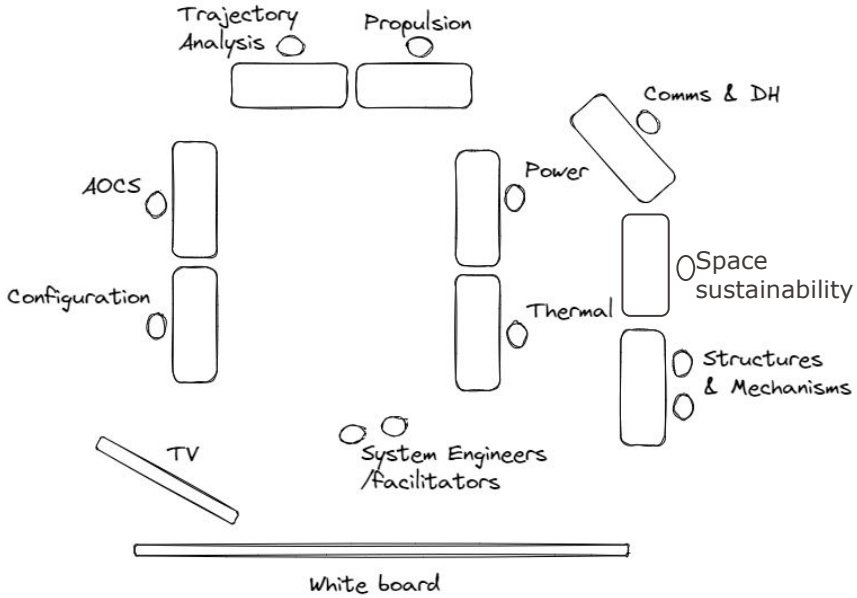
Figure 3 - The ESA/ESTEC Concurrent Design Facility Layout

M. Bandecchi et alli, "The ESA/ESTEC Concurrent Design Facility", proceedings of EuSEC 2000



ESA's Concurrent Design Facility in LEGO (see official instructions here)

eSpace's layout



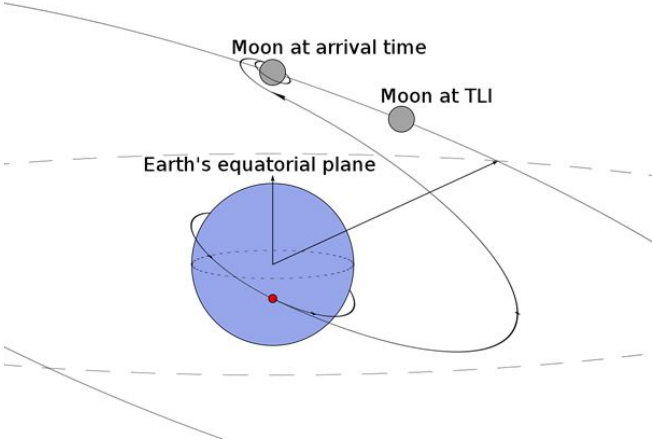
EPFL Space Center

Concurrent Design Facility

Expected results per sub-systems

Trajectory / Mission analysis

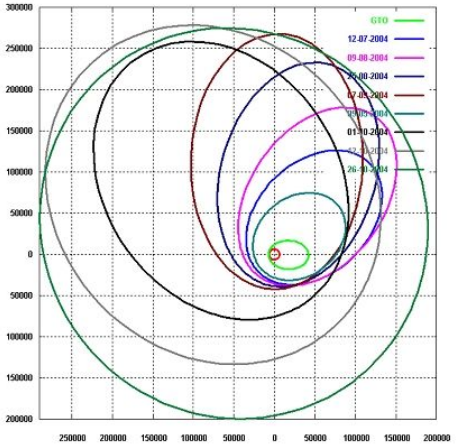
- Define and update the orbit and transfers of the spacecraft
- Define DeltaV over lifetime, DeltaV budget to be refined with systems team
- Calculate ground station contact time
- Calculate eclipse duration
- End of life management, support debris risks
- Support payload choice



Example of a trans-lunar injection

General Mission Analysis Tool (GMAT).
Use case here.

Or SPICE tool with its python wrapper



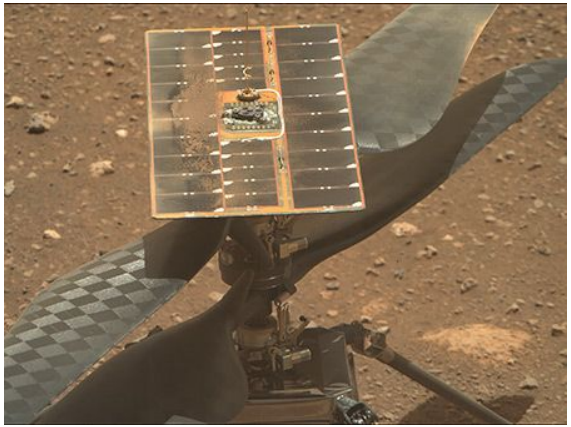
SMART-1 OSCULATING ORBIT

Expected results per sub-systems

Structures & Mechanisms

- Define the structure depending on the configuration
- Estimate the structural mass and the loads
- Separation mechanisms for companion spacecraft(s)
- Solar Array drive mechanisms
- Identify possible need for other mechanisms
- Mechanism design
- Mass budget of the subsystem

Beyond Gravity, platform mechatronics



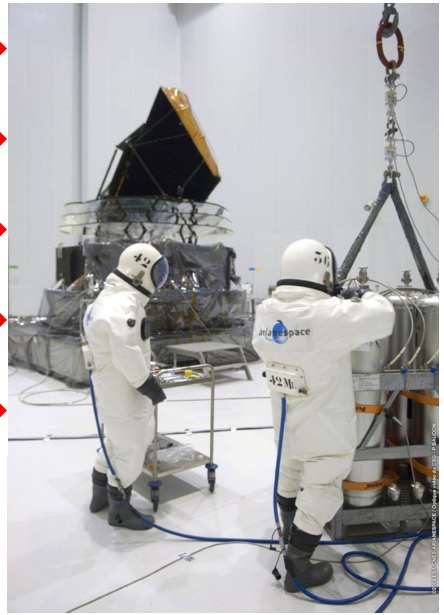
Maxon's motor for the Ingenuity mars helicopter

D_Orbit's Ion satellite carrier

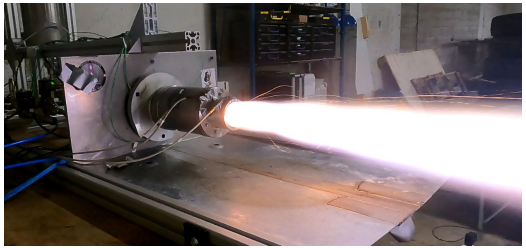
Expected results per sub-systems

Propulsion

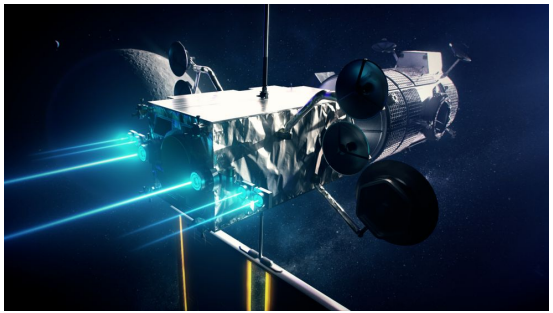
- Based on the DeltaV necessary for the mission, define the propulsion system:
  - Propulsion type (Chemical vs. electrical?)
  - Propellant type (“Green” propellant?)
  - Type of thrusters, sizing
  - Type of tanks, materials, sizing
  - Pipes (passivation?)
- Compute and update subsystem mass (also considering wet/dry mass)
- Subsystem power budget



"Green" satellite fuel - ESA



Credit: EPFL Rocket Team



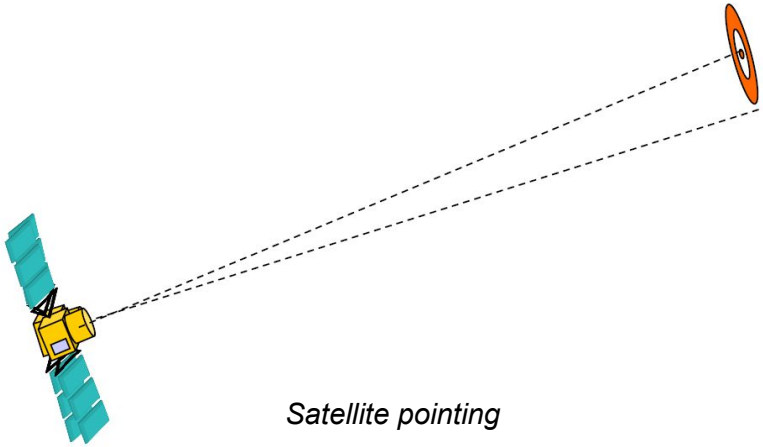
Electrical Propulsion blog article - NASA

Expected results per sub-systems

Attitude and Orbit Control System (AOCS)

Select equipment based on pointing requirements and attitude control requirements

- Sensors
  - Star Trackers
  - Sun sensor
  - Gyrometer
  - Navigation camera
  - ...
- Actuators:
  - Reaction wheels
  - Control moment gyroscopes
  - Thrusters
  - Solar sailing
  - …
- Subsystem mass and power budget



Satellite pointing

Star tracker - SODERN

CubeSat Magnetorquer

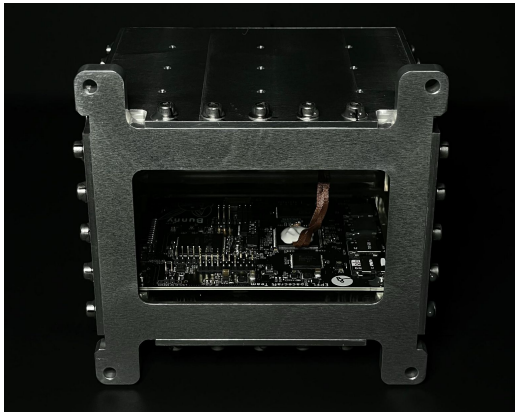
Reaction Wheel - Gomspace

Expected results per sub-systems

CDHS (Communication and Data Handling Systems)

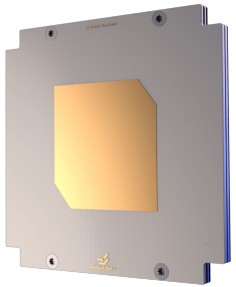
- Define the equipment needed based on the data rates needed for ground station contact and ISL (also considering the redundancies)
  - Antenna(s)
    - S band
    - P band
    - Inter satellite link
  - Mass Memory
  - Define the OBDH hardware

- Define the link budget
- Define mass and power budgets



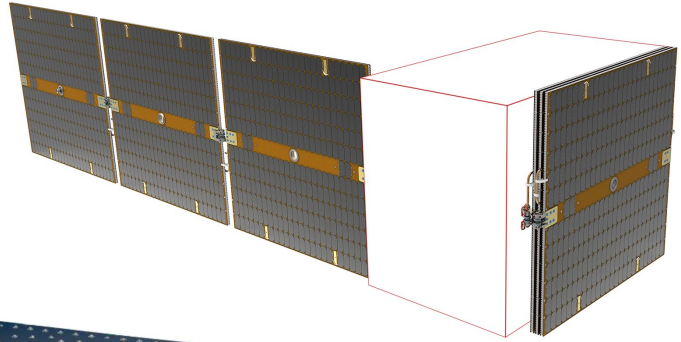
Bunny-1 On Board Computer - EPFL Spacecraft Team

GOMspace NanoMind A3200



S band patch antenna - EnduroSat

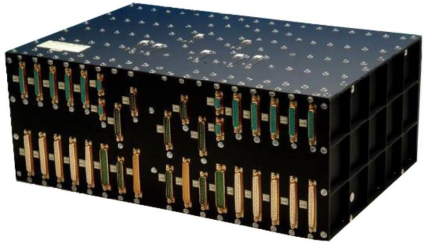
Expected results per sub-systems



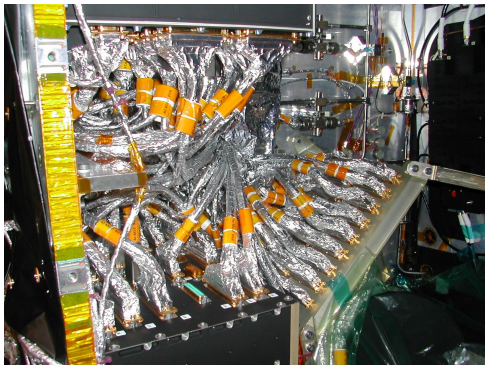
Satellite solar panels - Sparkwing

Power

- Design equipment based on the total power budget in the satellite
  - Solar array design and sizing
  - Battery (primary, secondary)
  - PCDU
  - Cable harness
- Power budget for the different modes to be made with systems team and experts
- Electrical passivation of the spacecraft
- Output and update the sub-system mass, communicate it with the systems team



Power Conditioning and Distribution Unit, copernicus satellite

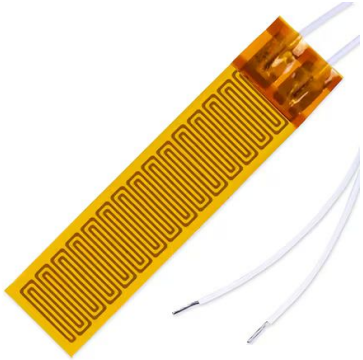


Inside the right wall of Mars Express. Credit: ESA

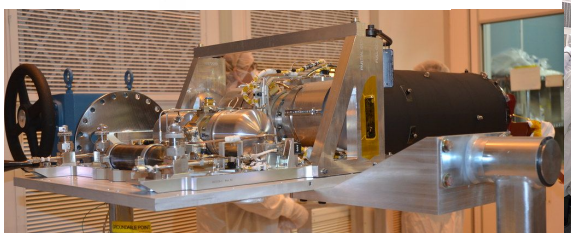
Expected results per sub-systems

Thermal

- Compute the thermal balance
- Help configuration with the placement of equipment with difficult thermal requirement
- Define the thermal equipment
  - MLI
  - Paint
  - Heat pipes
  - Radiators
  - Heaters
  - Coolers
  - ….
- Define and update sub-system power and mass budget



Polyimide Heater - OMEGA

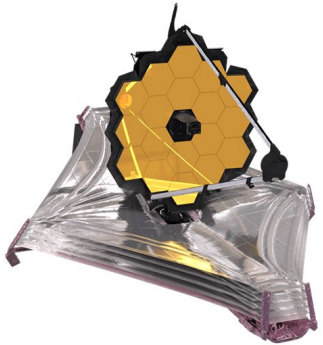


Cryocooler for James Webb Space Telescope - NASA

Multi-Layer Insulation (MLI)

https://www.jwst.nasa.gov/content/webbLaunch/whereIsWebb.html

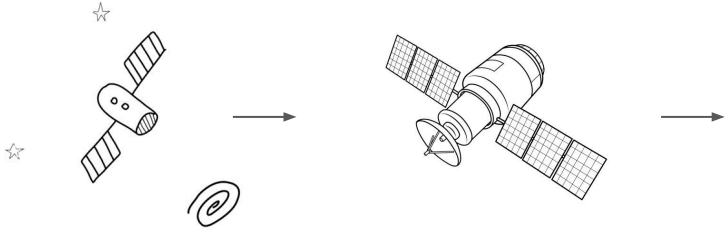
Expected results per sub-systems



https://www.nasa.gov/feature/goddard/2020/first-look-nasa-s-james-webb-space-telescope-fully-stowed

Configuration

- Close to systems engineering
- Create the configuration**s** of the spacecraft
- Define the location of the equipment in the satellite
- Determine the MoI and CoG
- Verify external interfaces



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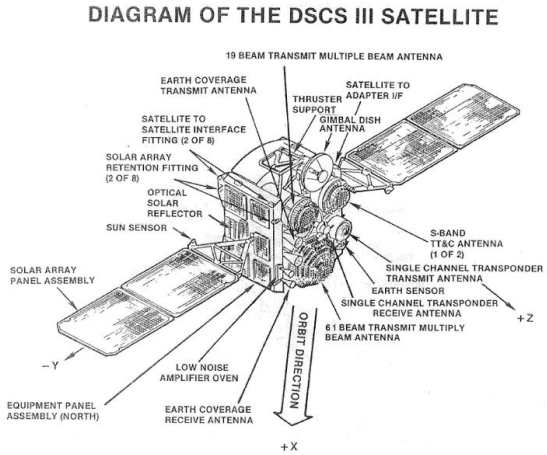


https://commons.wikimedia.org

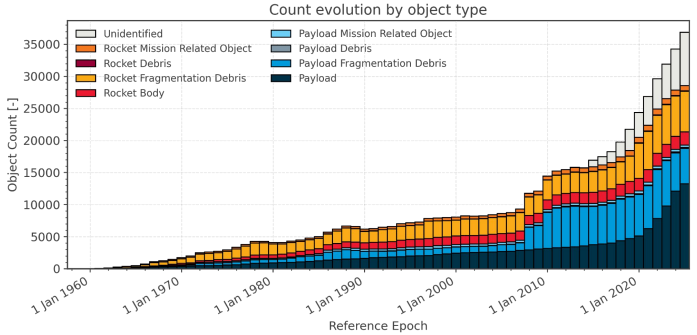
→ A coherent configuration schematized in a simple manner* is preferred over a CAD model that would be hard to iterate on.

*simple shapes, 2D diagrams, tangibles (e.g. LEGO®), … CAD if fluent

Expected results per sub-systems

Sustainability

- Close collaboration with systems engineering
- Space debris risks and end-of-life management
- Criterias about impacts on Earth environment
  - Life cycle inventory
  - Duplicate model on LCA software (Activity Browser)
  - Ecodesign choices
  - Launcher selection
- Sustainability benefits *from* the space mission ?



ESA space environment annual report

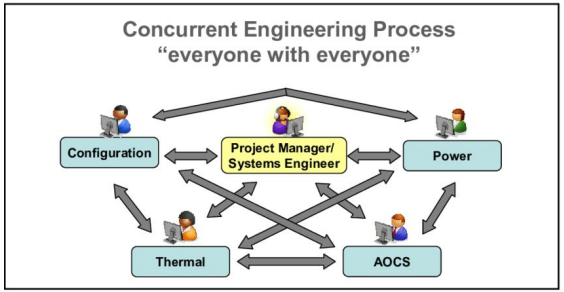
https://blogs.esa.int/cleanspace/

Martin Lemaire (PdS)

Expected results

Systems engineering

- Translate needs into requirements
- Update mission ConOps
- Keep track of technical assumptions
- Coordinate all subsystems
  - Manage the Push (submit) → publish → pull (synchronise) loop on COMET
- Manage the mass (and cost) budgets (+ support power, link, data budgets)
- Identify and quantify risks
- Choose payload characteristics



Source: Volker Maiwald et al. (2010) "DLR Feasibility Study SolmeX - CE Study Report"

Subsystems summary

Subsystems	Calculation sheets	User manual
Trajectory / Mission analysis	ESA	
Configuration	-	
Structures & Mechanisms	2x ESA	
Propulsion	ESA	✔
Attitude and Orbit Control System (AOCS)	ESA	✔
Communication and Data Handling Systems (CDHS)	2x ESA + eSpace	✔
Power	ESA	✔
Thermal	ESA	
Sustainability*	-	

Each ESA file has:
- Cover
- Change log
- Objectives
- Product tree
- Trade-off
- (Constants)

Require values *from* COMET
Outputs values *to* COMET

*test of internal tools, process part of a semester project

How

Team

You will be ALL part of the same **team.**

Your team will be tasked with the design of **a mission** and provided with a **data pack** (i.e., basic background information about the design problem and selected resources).

This is a **cooperative challenge**.

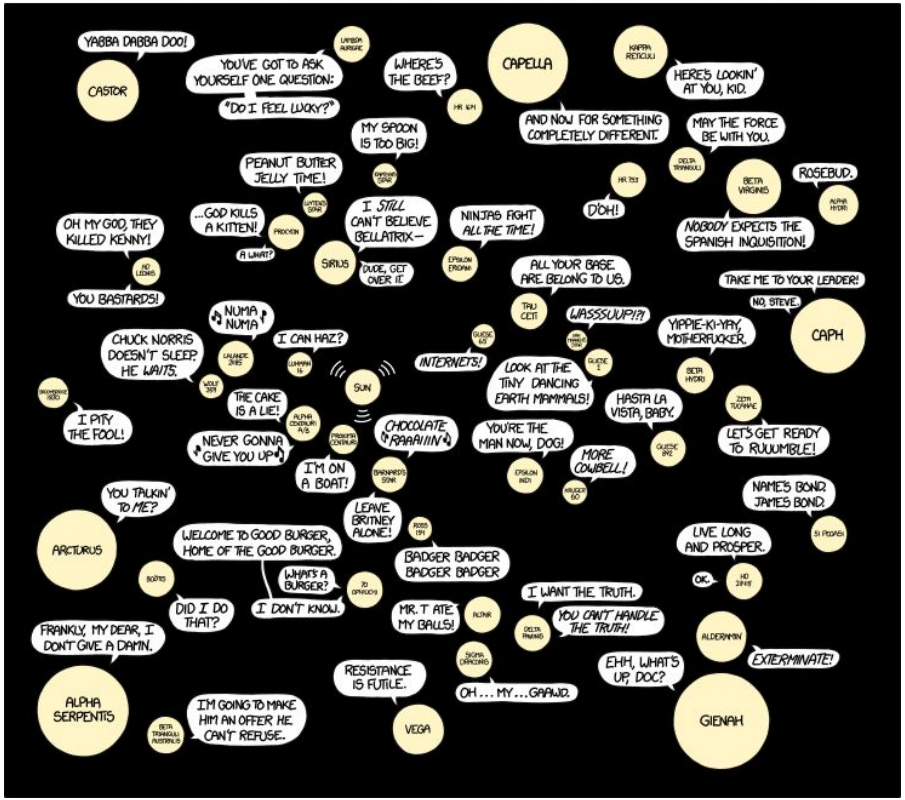
On the last day of the course, your team will **present its own final mission design**.

There are no right or wrong solutions.

Specialty
System Engineering
Propulsion
C&DH
AOCS
Configuration
Thermal
Structures & Mechanisms
Power
Trajectory Analysis
(Sustainability)

Roles will be assigned next week (trying to fulfill your **preference**)

IF OTHER STAR SYSTEMS ARE LISTENING IN ON OUR POP CULTURE,
GIVEN THE SPEED-OF-LIGHT DELAY, THESE ARE THE JOKES AND CATCHPHRASES
THEY JUST LEARNED ABOUT AND ARE CURRENTLY REPEATING WAY TOO MUCH:



https://xkcd.com/1212/

COMET Tutorial

- Introduction
- Roles & domains
- Model
- Ownership & subscription
- Three switch mechanism
- Excel add-in

https://products.rheagroup.com/comet

COMET - a hub & spoke software

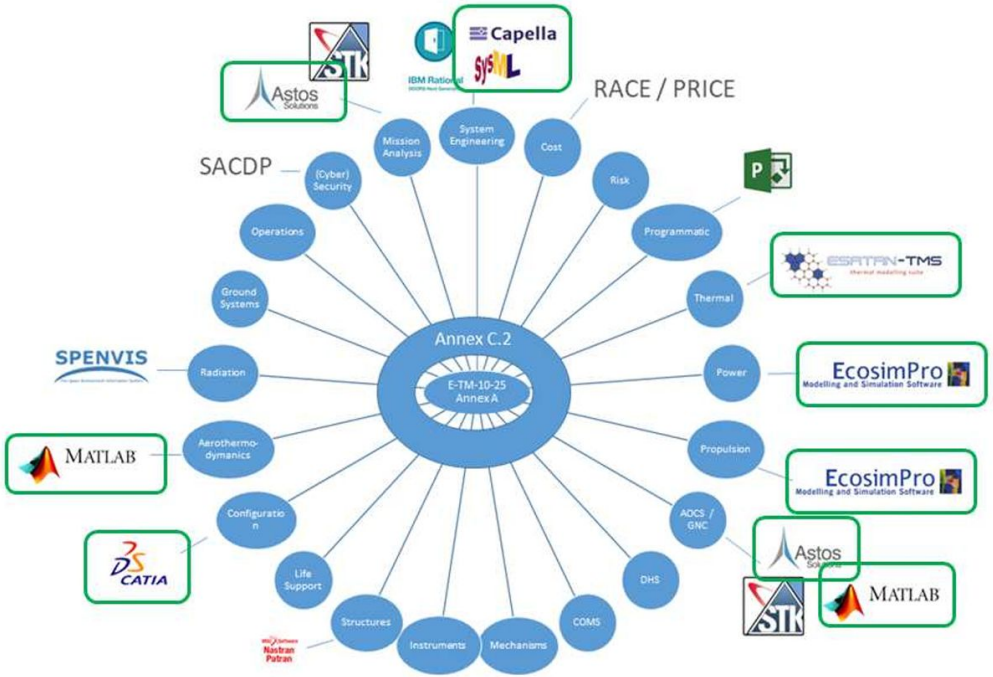


Figure 2: Digital Engineering Hub

Source: Starion Group's COMET CDP4 manual (version 29/08/2024)

COMET - Public server

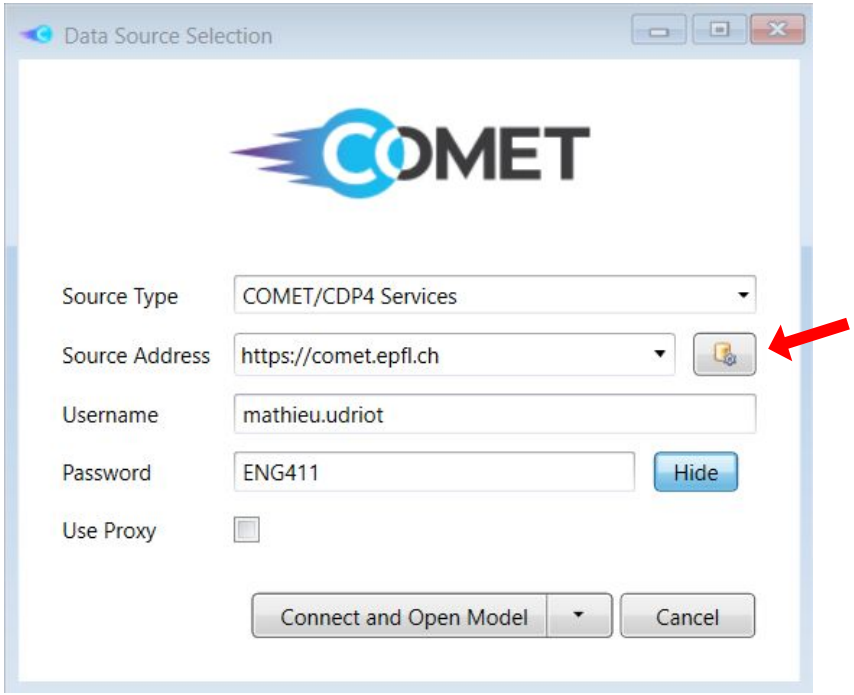
A public server

Login 

- Username: admin
- Password: pass

Connect to the model (https://comet.epfl.ch)

Activate auto refresh



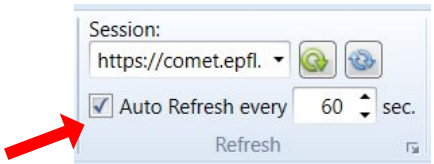
COMET tutorial - Introduction

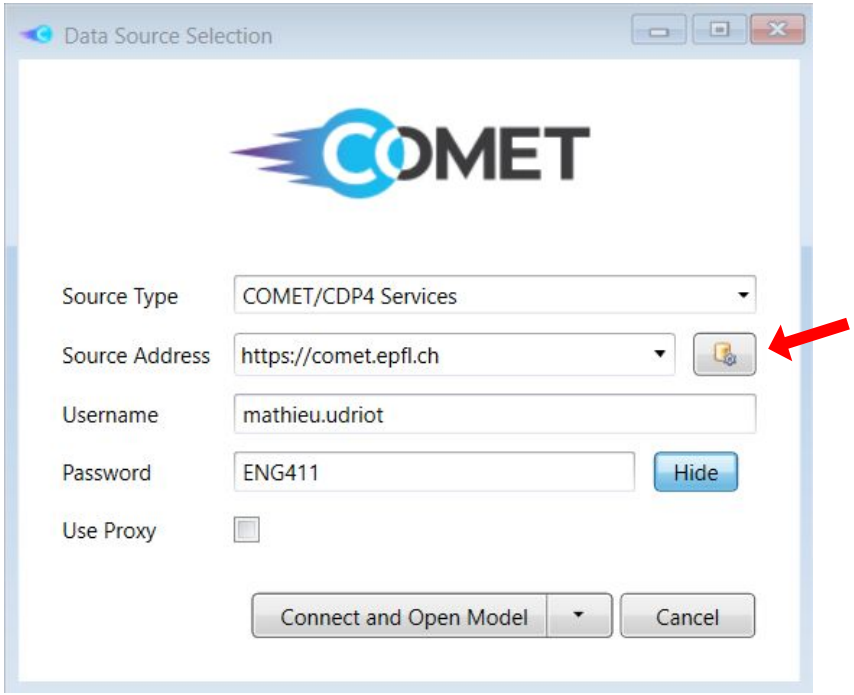
Login 

- name.surname
- Password: ENG411

Connect to the model (https://comet.epfl.ch)

Activate auto refresh

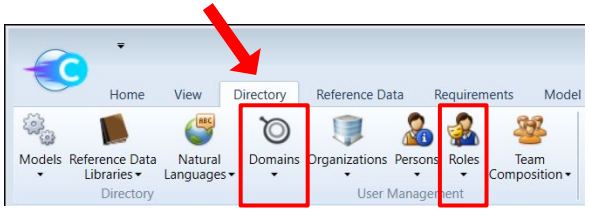




COMET Usernames & subsystems

Name	COMET user name
Alexandre Rafael Aires Viegas	alexandre.airesviegas
Jehan Névé Marc Corcelle	jehan.corcelle
Daniel Simon Christoph Gann	daniel.gann
Aurélien Genin	aurelien.genin
Adam Neale Antonin Lecroart	adam.lecroart
Martin Jacques-Yves Lemaire	martin.lemaire
Yijun Liu	yijun.liu
William Martin	william.martin
Aubin Louis Gérard Mercier	aubin.mercier
Tom Lennart Rathjens	tom.rathjens
Alexis Guillaume Sylvain Ruprecht	alexis.ruprecht
Samuel Arthur Wahba	samuel.wahba

COMET tutorial - Roles & domains



Person Roles for COMET Site (permission on COMET server)

- CD Team members
- Site administrators

Participant Roles per Engineering Model

- Domain experts (subsystems)
- Design authority (systems engineers)
- Model administrators

Domains

- The existing subsystems / expertise →

Name	Short Name
Aerothermodynamics	AER
Attitude and Orbit Control	AOC
Attitude and Orbit Guidance, Navigation and Control	AOGNC
Communications	COM
Configuration	CON
Cost Engineering	COS
Data-Handling	DHS
Descent and Landing System	DLS
Electric Propulsion	ELPRO
Electro-Magnetic Compatibility	EMC
Entry, Descent and Landing	EDL
Ground Systems Engineering	GS
Guidance, Navigation and Control	GNC
Instruments	INS
Life Support	LS
Mechanisms	MEC
Mission Analysis	MIS
Power	PWR
Programmatics	PROG
Propulsion	PRO
Pyrotechnics	PYR
Radiation	RAD
Risk Management	RISK
Robotics	ROB
Simulation	SIM
Structures	STR
System Engineering	SYS
Thermal	THE
Thermal Protection System	TPS
Trajectory	TRA

COMET tutorial - Models & building blocks

"Model" = "physical or abstract representation used for calculations, predictions or further assessment"

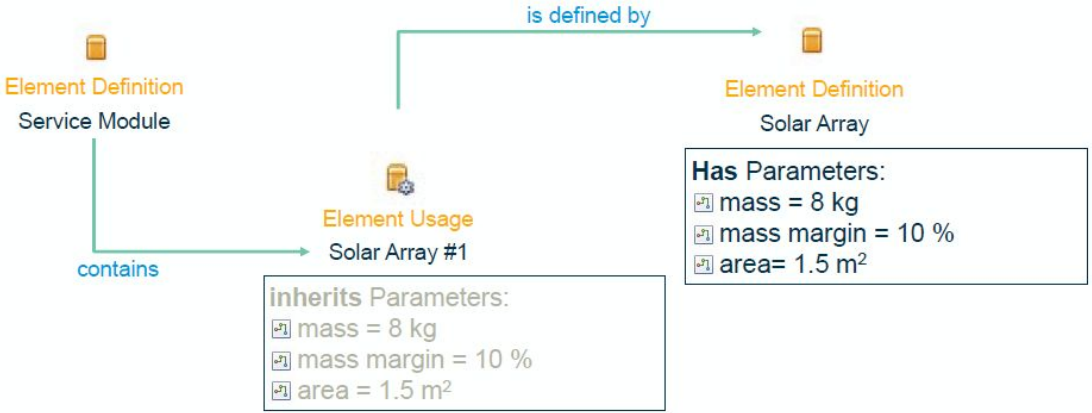
- ECSS-S-ST-00-01C

In COMET: a model is made with **elements definitions** (=~classes)

Elements definitions are characterized by **parameters** (type mass, volume, etc. and unit)

There can be several similar elements used in a model (**element usage** in the product tree =~instances)

Reference data library (RDL) to hold predefined generic data (types, units, scales, categories, etc.)



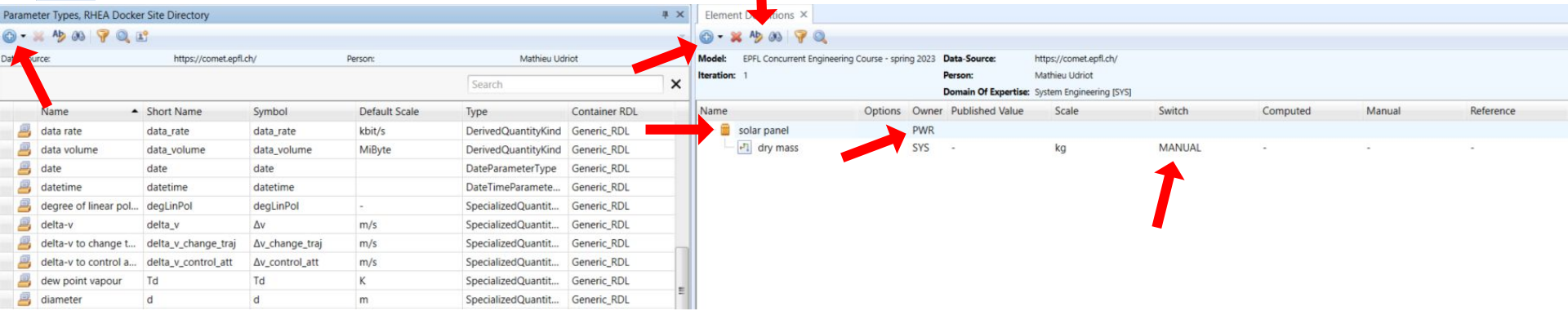
COMET Tutorial - Elements definition

Parameter Types

Reference data > Parameter types

Element Definitions

Model > Element Definitions



1. Go to Model > Element Definitions
2. Create new element definition (All Element Definitions are made on the same level)
3. (Open Reference data > Parameter types, create new parameter types)
4. Drag and drop parameter types, see **owner**
5. Can still modify or inspect
6. Select value switch
   - Manual: Your **initial** best guess
   - Computed: Value based on analysis or **datasheet**
   - Reference: Value to be used for comparison (rarely used)

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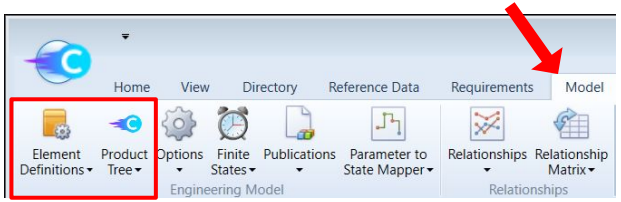
Concurrent Design Facility

COMET Tutorial - Elements usage



Element Definitions

Model: EPFL Concurrent Engineering Course - spring 2023 **Data-Source:** https://comet.epfl.ch/
Iteration: 1 **Person:** Mathieu Udriot
Domain Of Expertise: System Engineering [SYS]

Name	Options	Owner	Published Value	Scale	Switch	Computed	Manual	Reference
solar panel								
Solar panel structure		SYS						
length		SYS	-	m	MANUAL	-	-	-
mass		SYS	-	kg	MANUAL	-	-	-
dry mass		**SYS**	-	**kg**	**MANUAL**	-	**4**	**4**
test mission		SYS						
solar panel		SYS						
solar panel		SYS						
dry mass		**SYS**	-	**kg**	**MANUAL**	-	**4**	**4**
orbit type		SYS	-	-	MANUAL	-	-	-
Solar panel structure		SYS						
length		SYS	-	m	MANUAL	-	-	-
mass		SYS	-	kg	MANUAL	-	-	-

Product Tree, Option 1

Model: EPFL Concurrent Engineering Course - spring 2023 **Data-Source:** https://comet.epfl.ch/
Iteration: 1 **Person:** Mathieu Udriot
Option: Option 1 **Domain Of Expertise:** System Engineering [SYS]

Name	Value	Owner	Switch	De
test mission		SYS		
orbit type	-	SYS	MANUAL	
solar panel : solar panel		SYS		
dry mass	**- [kg]**	**SYS**	**MANUAL**	
Solar panel structure :...		SYS		
length	- [m]	SYS	MANUAL	
mass	- [kg]	SYS	MANUAL	
solar panel : solar panel		SYS		
dry mass	**- [kg]**	**SYS**	**MANUAL**	
Solar panel structure :...		SYS		
length	- [m]	SYS	MANUAL	
mass	- [kg]	SYS	MANUAL	

1. Open Element definitions and Product tree
2. SEs set the **top element** (mission test)
3. Drag and drop element definitions (to product tree or other element definition)

EPFL Space Center
Concurrent Design Facility

COMET tutorial - Ownership & subscription

Element Definitions are the building blocks of a COMET model, **owned** by the Domain of Expertise that has created it
→ Responsible to keep it up to date

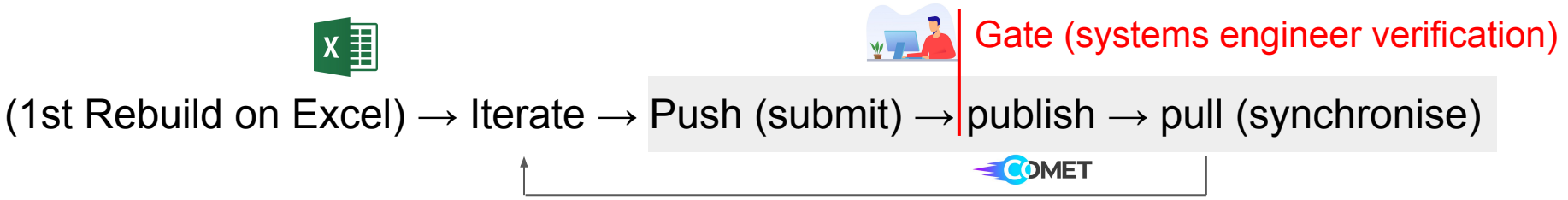
A **parameter** is always **owned** by one Domain of Expertise
→ Responsible for its existence and for keeping it up to date
→ It can be used - **Subscribed to** - by other Domains of Expertise

Right click > Subscribe to this parameter

Element usages inherit and change automatically

Which parameters do you need ?
Which one do you own that the others need ?

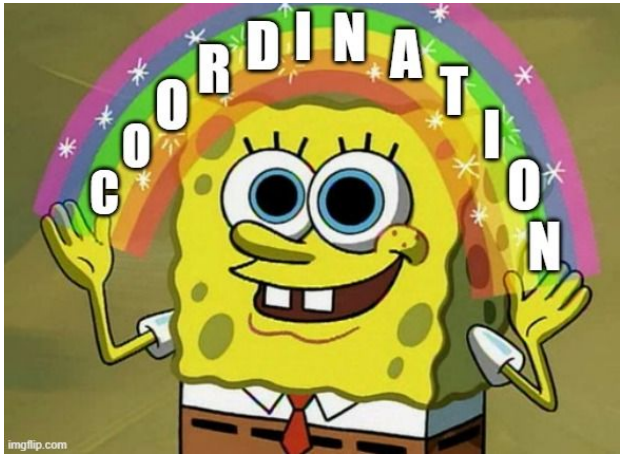
COMET tutorial - Three switch mechanism



When do we publish? (by Design Authority)

- At the end of a session
- (At the end of a Domain Expert's presentation)
- On request

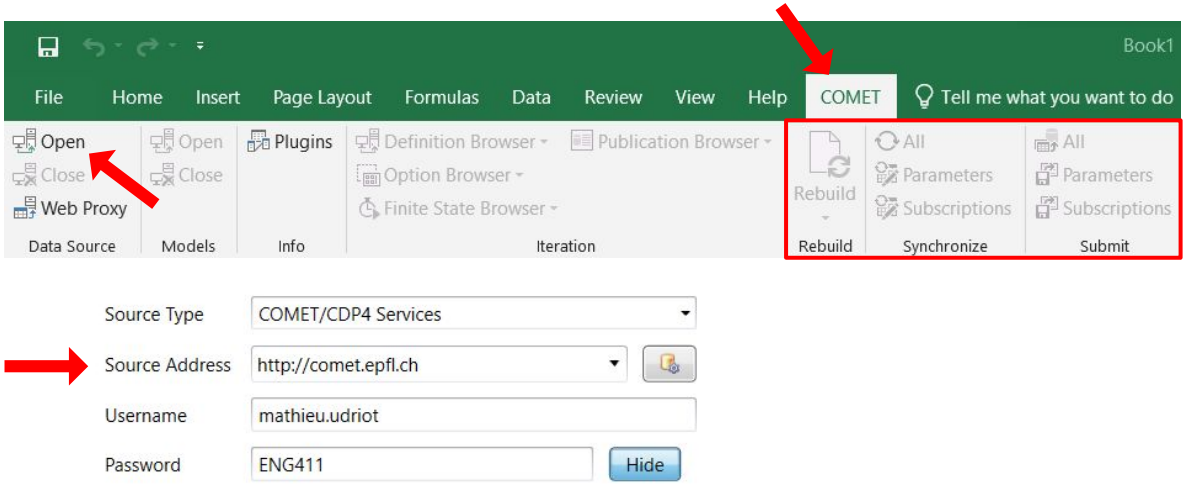
<u>Best practice</u>: alert people when your data is updated (pushed, ready to publish)



COMET tutorial - Excel add-in

Log to COMET from Excel add-in

Open the model
Server path: https://comet.epfl.ch
Note: do not add “www”

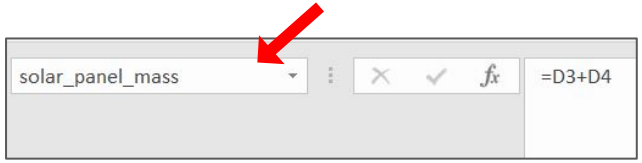


“Rebuild” to create the Parameters and Option sheets

“Synchronize” to **pull** data

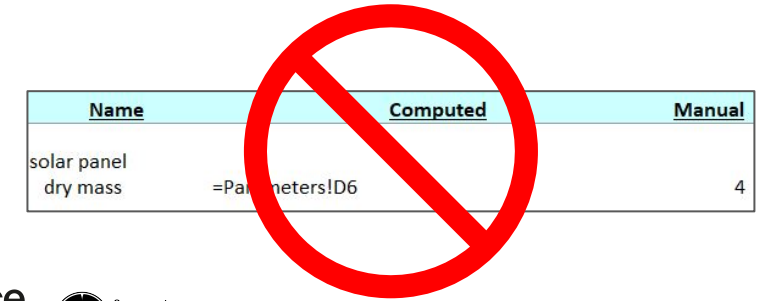
“Submit” to **push** → The outputs (Parameter values) are transferred to COMET via the Parameters worksheet

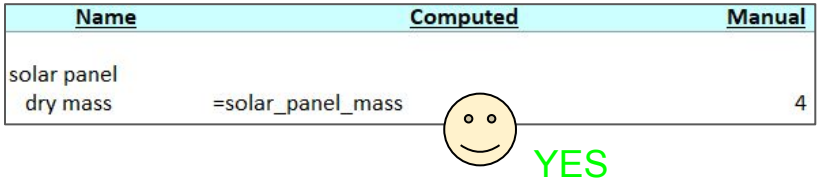
COMET tutorial - Excel add-in



How to iterate:

- Rebuild (or synchronise if rebuilt already)
- See “owned” and “subscribed to” parameters
- Compute values of **owned** parameters
- Create a **stable** link to the Parameter sheet → use symbolic cell names !
- Fill the “Computed” and “Manual” field of the target parameter
- Toggle switch
- Submit to COMET
- Publication by design authority

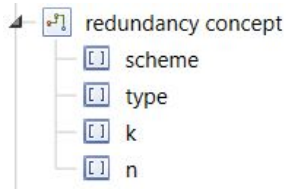




COMET tutorial - Advanced modelling

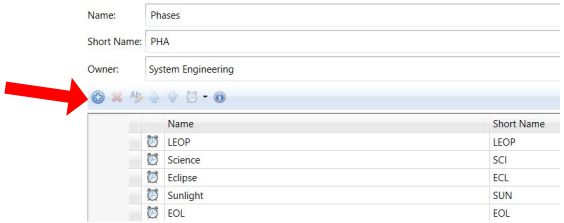
Redundancy **concept** parameter includes:

- red_**scheme** (hot - all units are on, or cold - k units on)
- red_**type** (internal - redundant units all in single package, or external - explicit)
- **k**_out_of_n_items : number of units needed for nominal operation
- **n**_items : total number of units in system

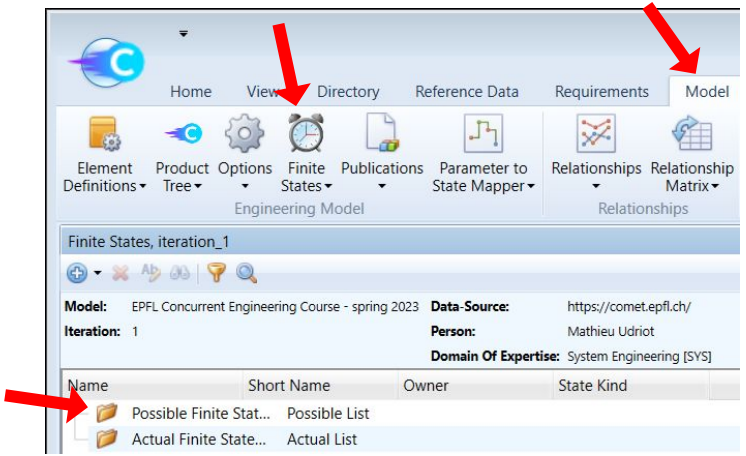


State dependency:

- Create list of **possible** finite states



- Define list of **actual** finite states
  - Select 2 or more possible lists
  - Change state kind to “forbidden” is not allowed
- Define parameter state-dependant value



CDF wiki and report

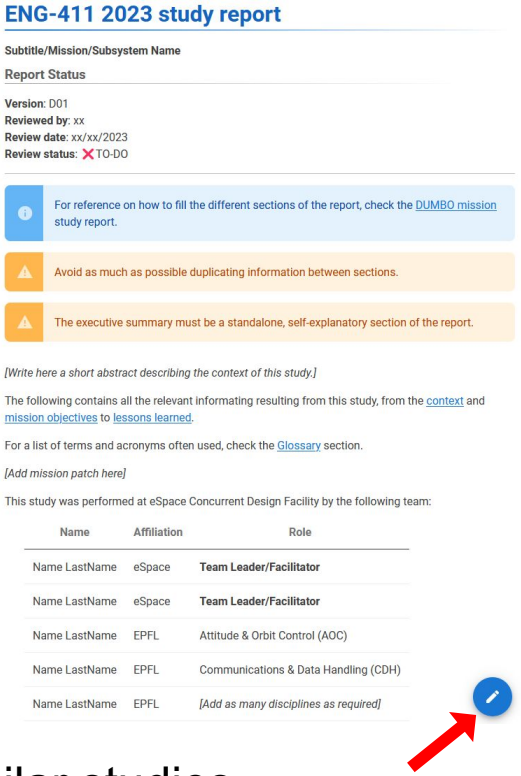
Connect to https://cdf.epfl.ch/ to edit

- name.surname@epfl.ch
- ENG411

Go to "previous CE studies → ENG-411 2025 study report"

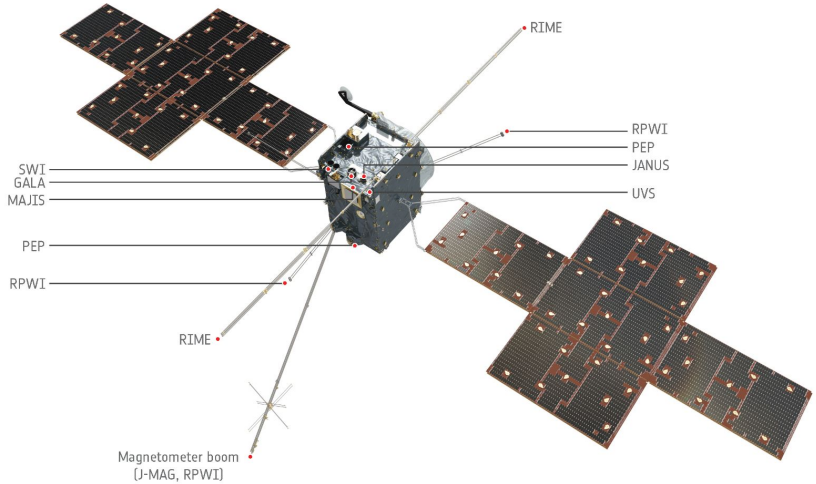
How to write the report:

- Markdown language
- Each subsystem has its report section
- Keep track of iterations, justify decisions
- Executive summary to be written at the end
- Technical lessons learnt = main takeaways for future, similar studies



Wrap up

- Summary of subsystems making the team and the available tools
- Remind concurrent process - three switch mechanism: **push, publish, pull**
- Where to find the COMET user guide:
  - Here is the 2024 version of the User Guide
  - Or (if the above link does not work), go to COMET's Github page, and find the hyperlink to the User Guide in the README



JUICE mission: launch planned on April 13th 2023, was studied in the CDF in 2005 (as "Laplace", see poster)

Any questions?

Parting thoughts

First time this course is given at EPFL. There will be things to improve and polish.

We need your feedback!

We are here to help YOU learn. Anything you may need help with or on your mind on how to make the course better, let us know.

Contact: david.rodriguez@epfl.ch

[office hours in PPH 335, every Wed. 09:00-11:00/14:00-16:00]