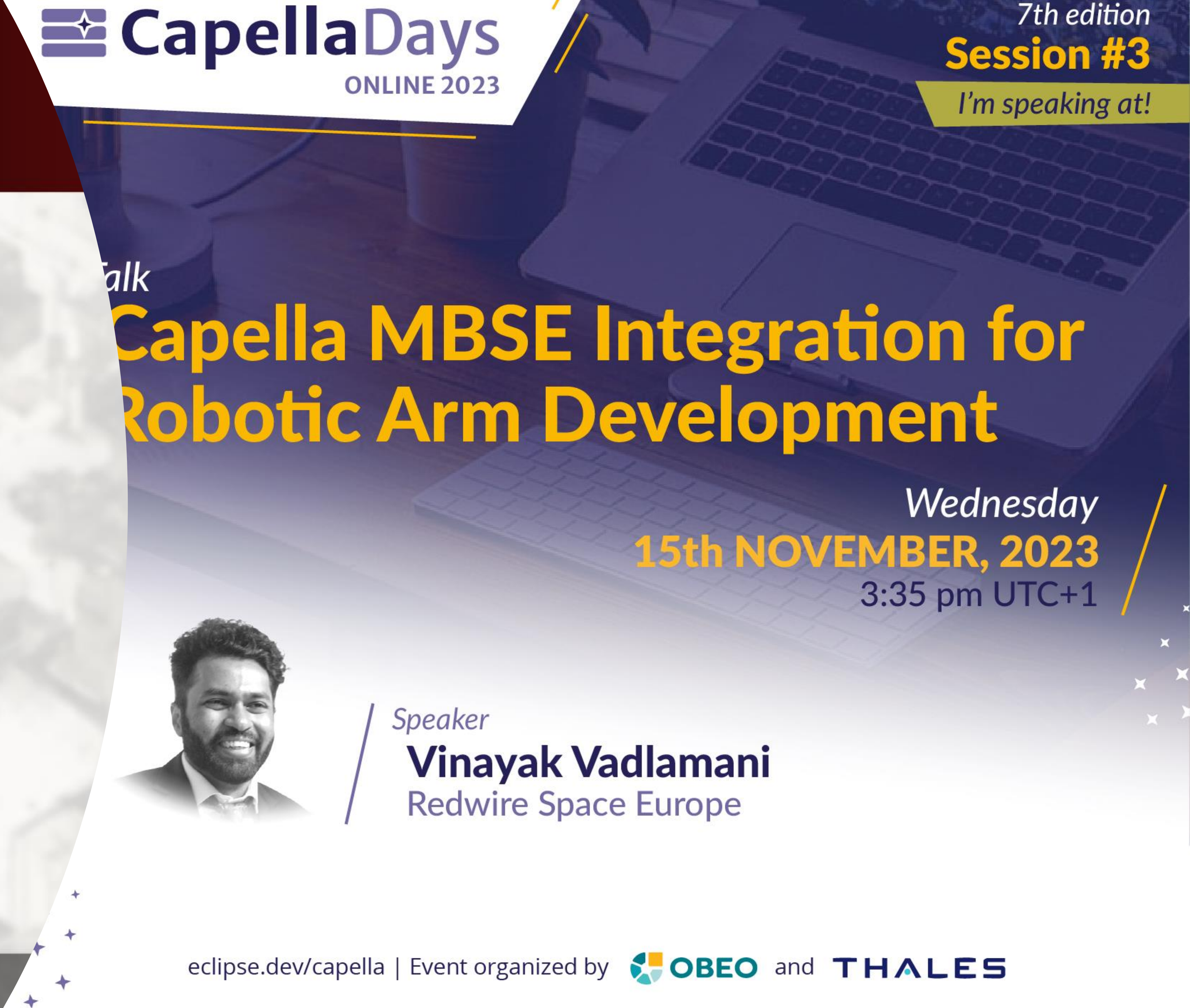
Capella MBSE Integration for Robotic Arm Development

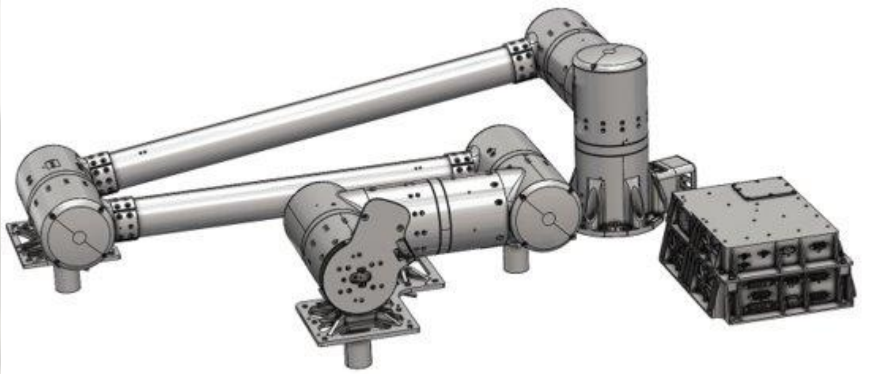
15 November 2023

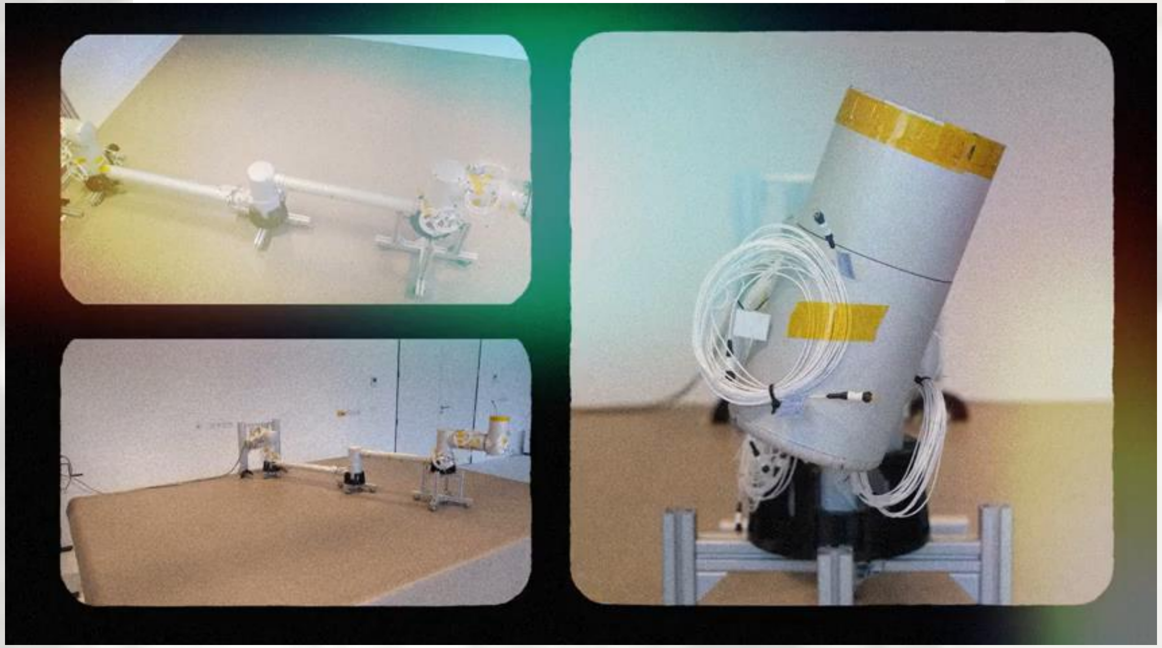
CapellaDays
Online 2023



Product

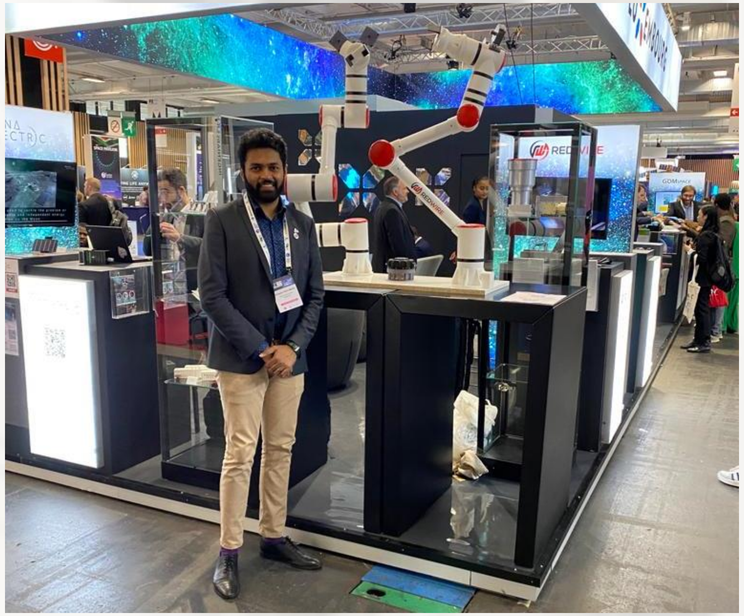
- Designed for sustainable **On-Orbit Servicing** and **In Space Manufacturing** applications
- *STAARK* robotic subsystem (TRL 6)
  - 6-DoF robotic manipulator
  - Robotic Control Unit
  - Hold Down and Release mechanism
  - Internal flight harness
  - Custom End effector interface
- Developed by MadeinSpace/Redwire Space Europe under the Luxembourg Space Agency LuxIMPULSE program



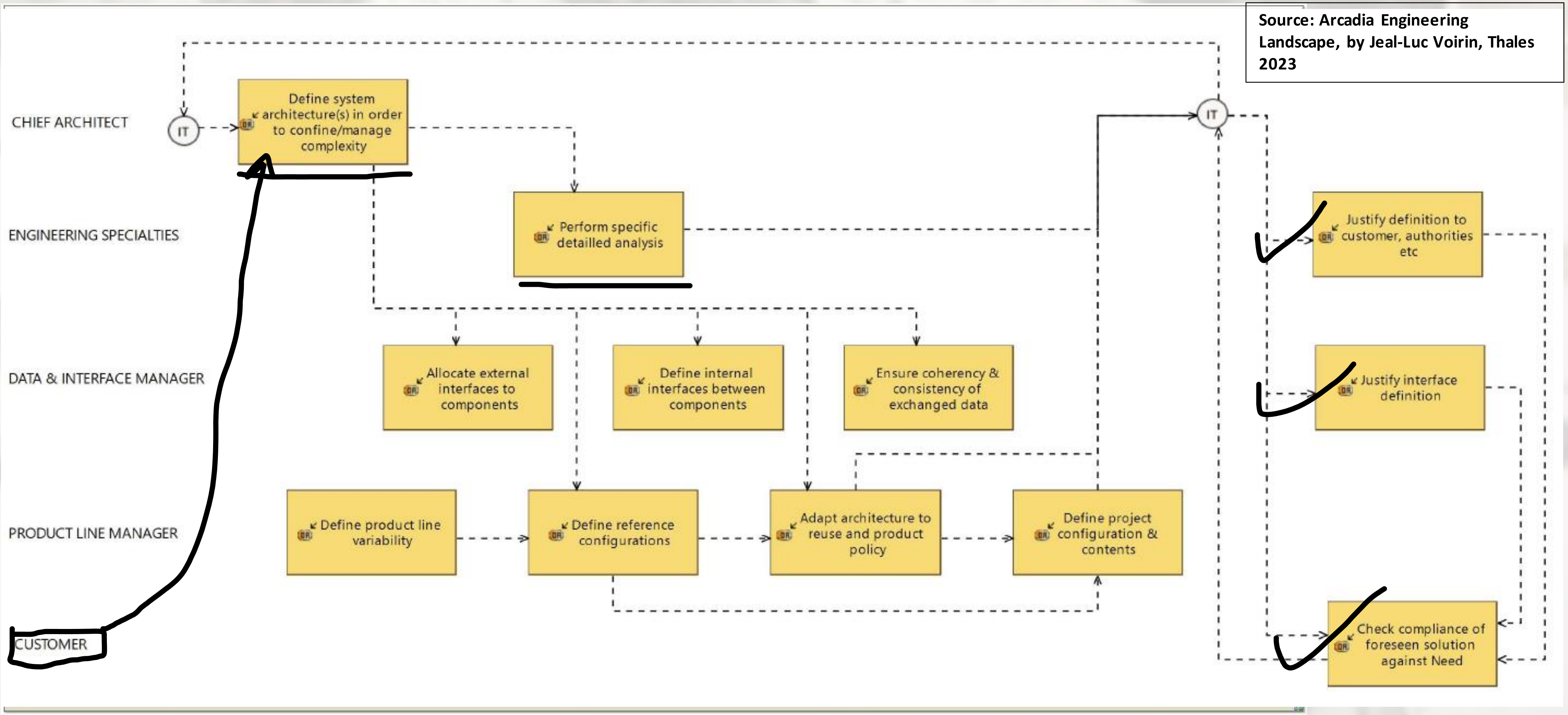


Speaker

- Lead Systems/Chief Engineer at Redwire Space Europe (till September 2023)
- 12 years experience in spacecraft systems engineering
- B.Tech in Aerospace, M.Sc. in Aerospace
- Currently getting a CSEP certification
- Focused primarily in space domain/upstream, also critical V&V for defense
- Model Based SE enthusiast (Capella/Arcadia since 2017), introduced MBSE to multiple companies
- Interests:
  - Autonomous space robotics
  - Verification & Validation for space
  - Formal verification of autonomy agents



Why MBSE, Why Capella?

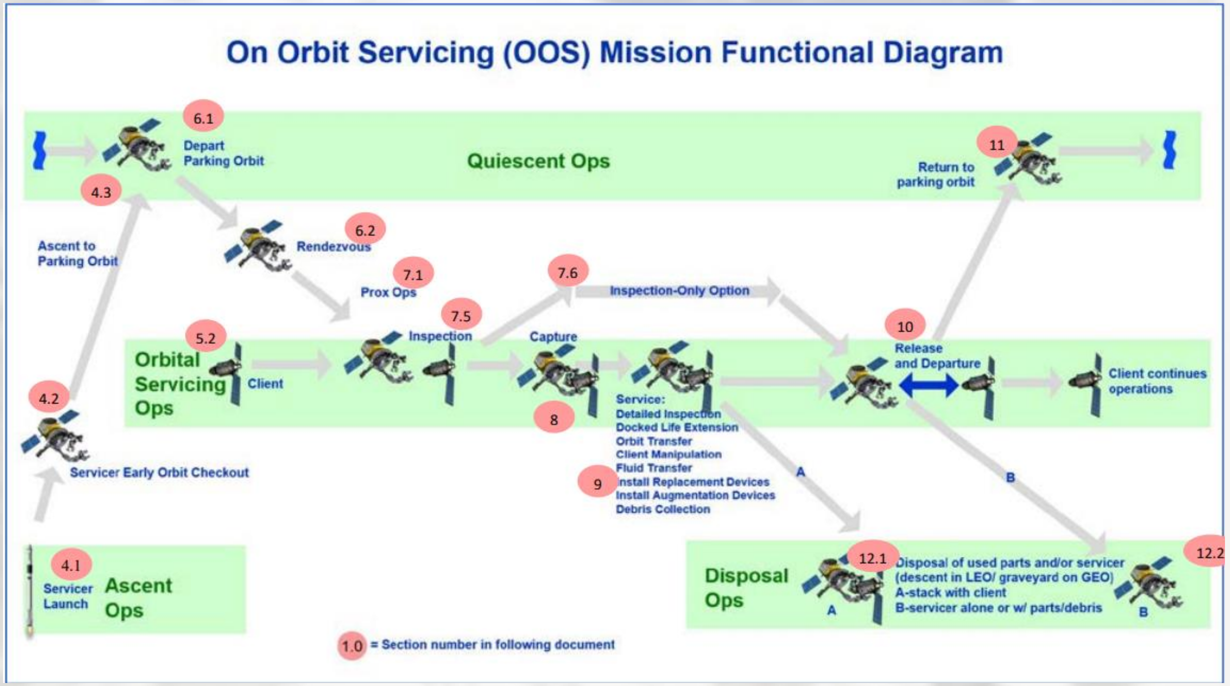


Source: Arcadia Engineering Landscape, by Jeal-Luc Voirin, Thales 2023

Robotics Servicing Architecture

- CONFERS – OOS Ontology
- SpaceLogistics – Practical Experts

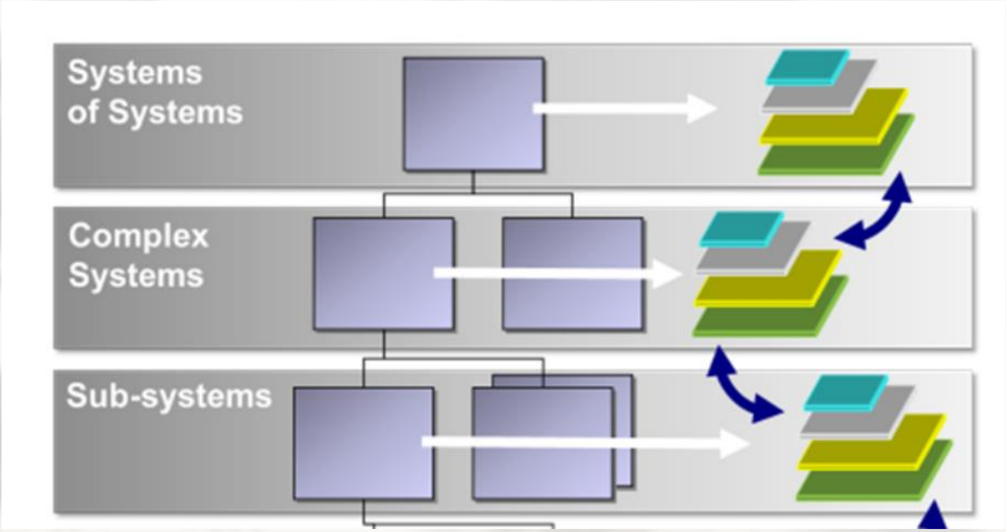
Source: SpaceNews report : Made In Space Europe and Momentus plan robotic spacecraft, Sep 2020



Source: CONFERS On-Orbit Servicing (OOS) Mission Phases, 2019

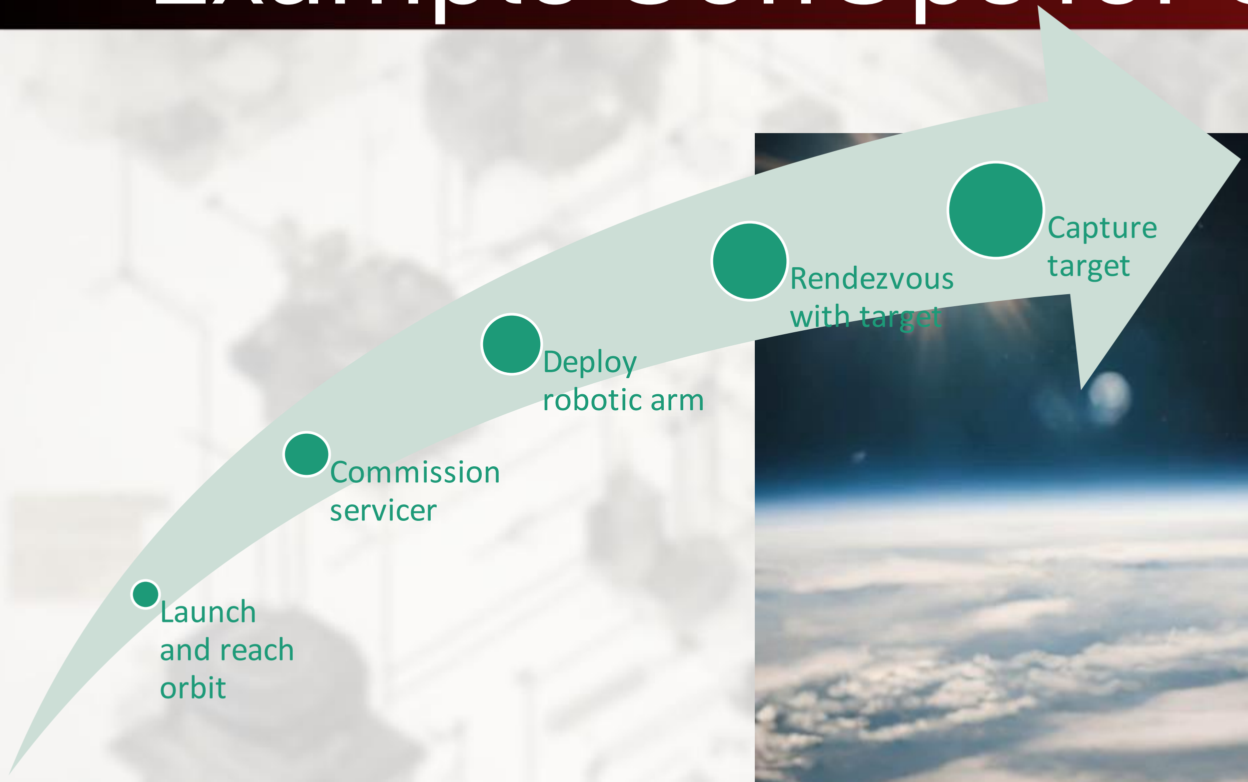
System of Interest

- A system that integrates the robotic entities, spacecraft and the Operator is the system of interest. (shown in SA later)
- This usecase does not plan to develop the physical or logical architecture of the system thereof
- However, the tradeoff for different system architecture variations was studied as a high level decision tool



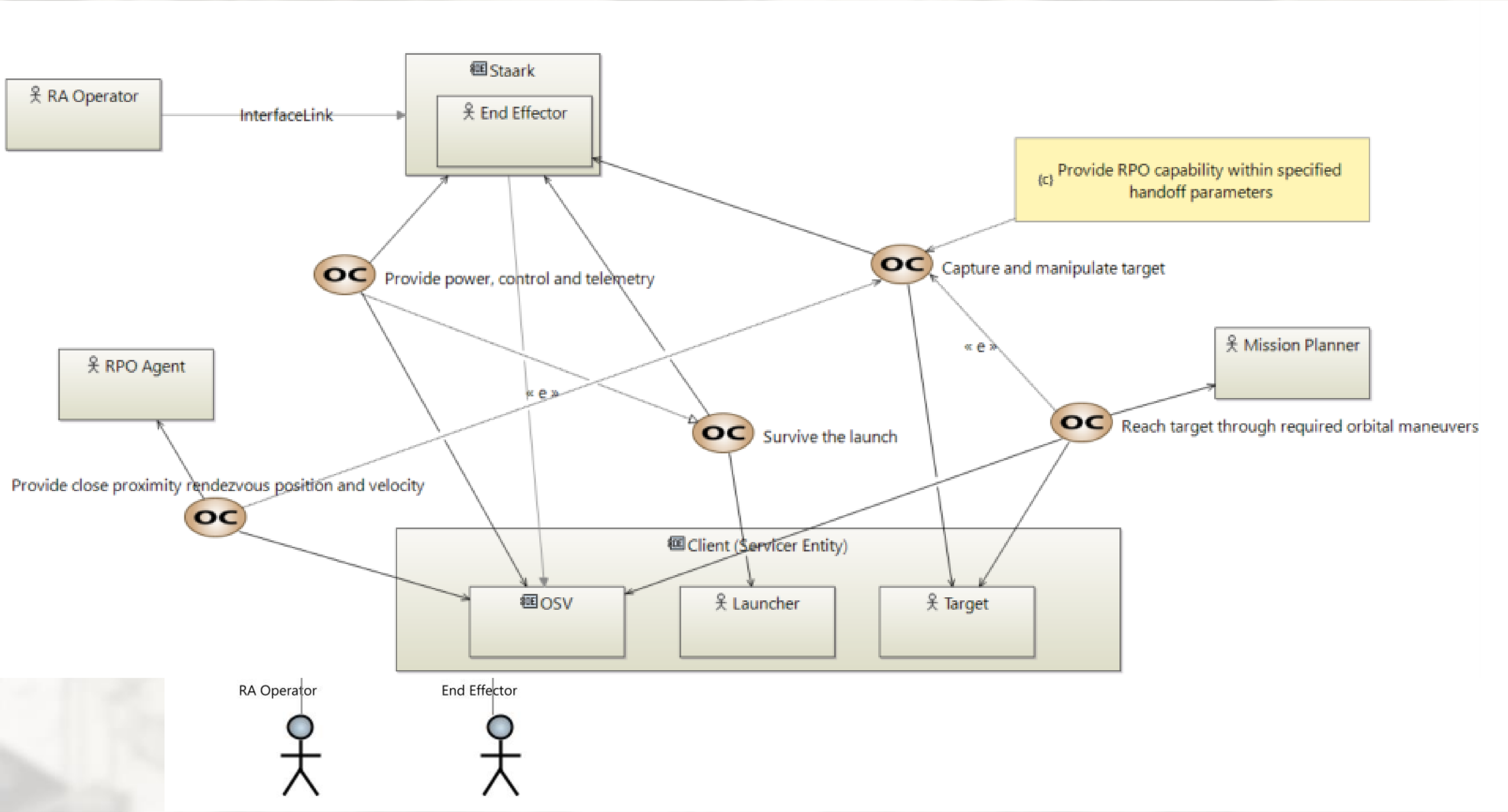
Source: Capella MBSE website

Example ConOps for Capella



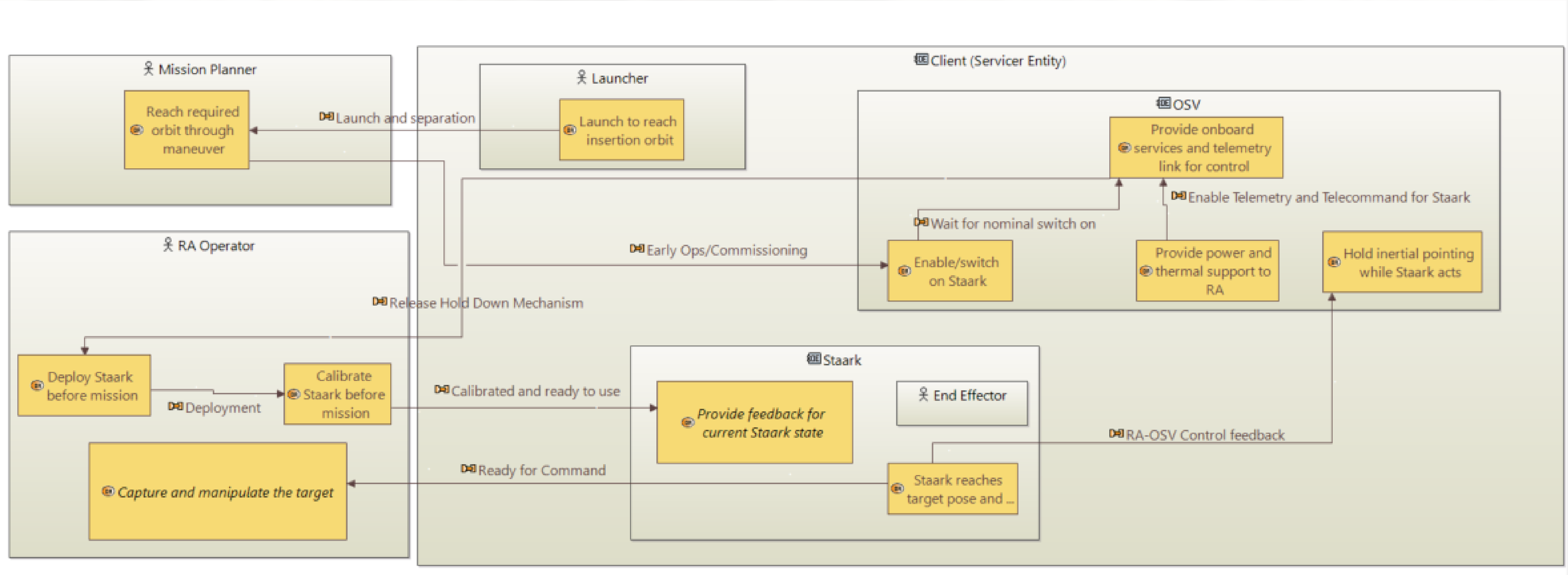
Operational Entities/Capabilities

- Staark – Robotic Arm
- OSV – Orbital Servicing Vehicle
- RPO – Rendezvous Proximity Operations
- Launcher – Launch Vehicle
- Mission Planner – Developer of flight path, mission operations
- RA Operator – Robotic Arm Operations Actor
- End Effector – Tool placed at tip of robotic arm to manipulate/act



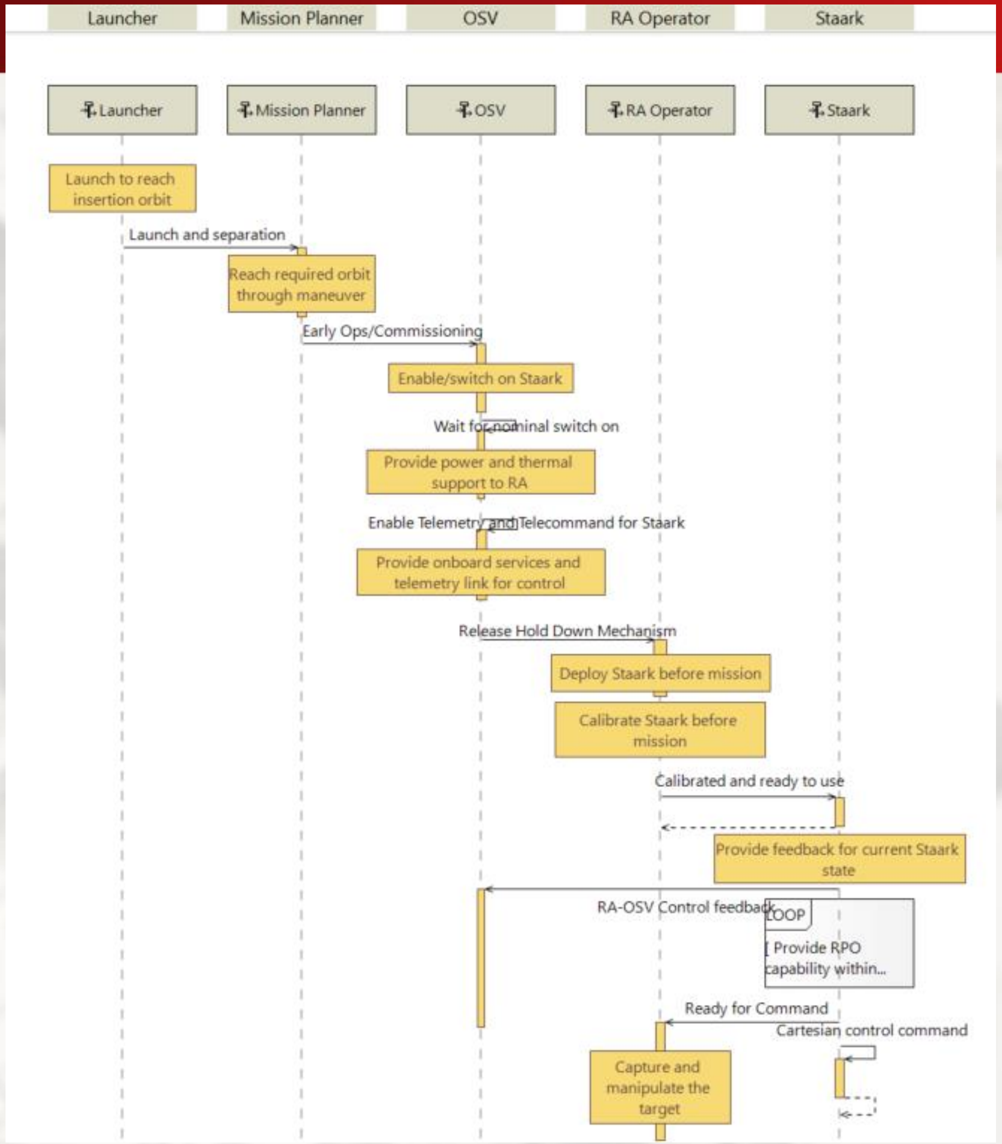
Operational Analysis

- Operational VP – Assigning OA to every entity/actor
- Is an entity missing? Is an actor missing?



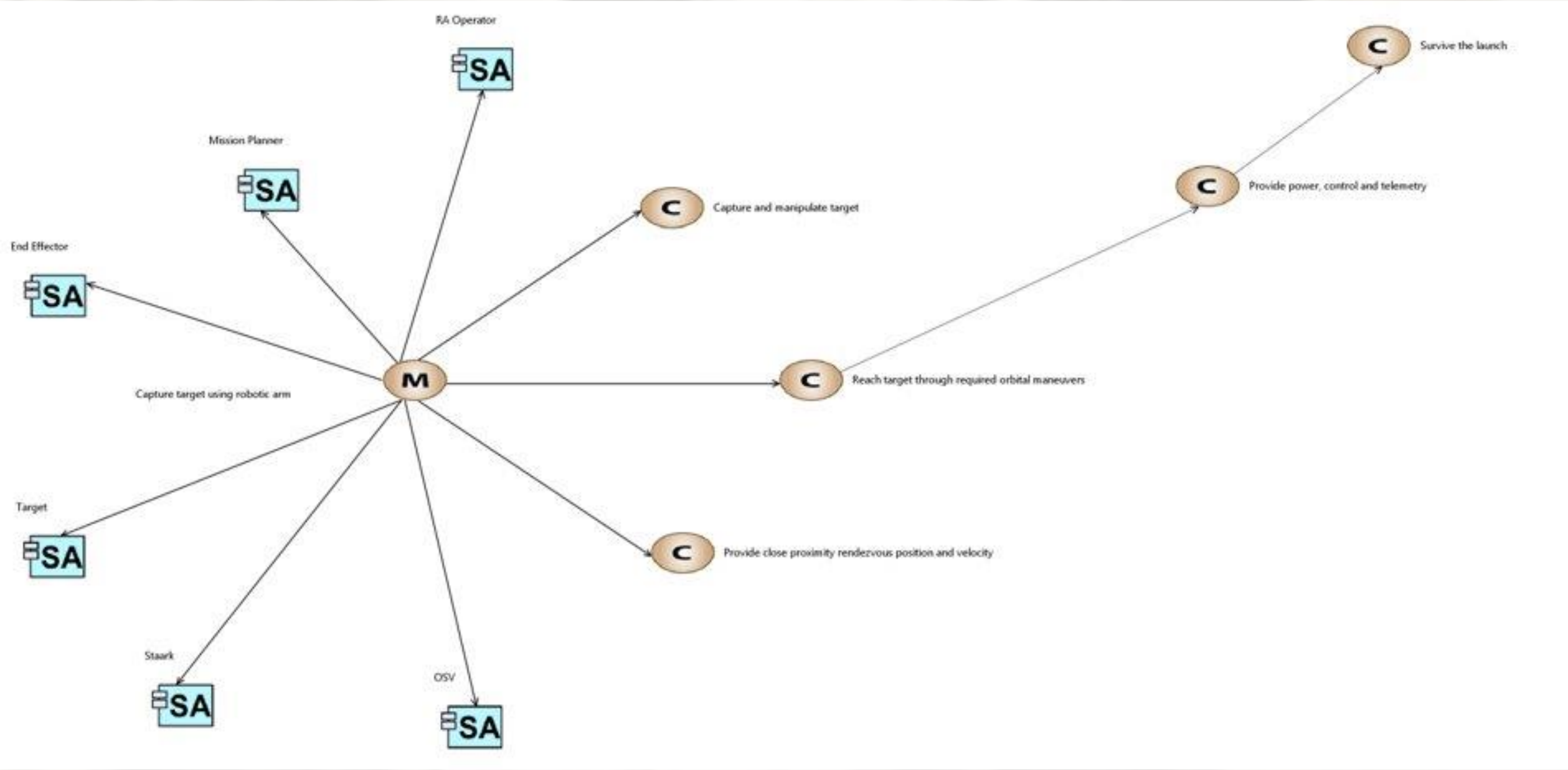
Operational Sequence

- Sequence is based on a primary mission where
  - Arm needs to be commissioned
  - Arm needs to be deployed and calibrated
  - Arm needs to be navigated and controlled

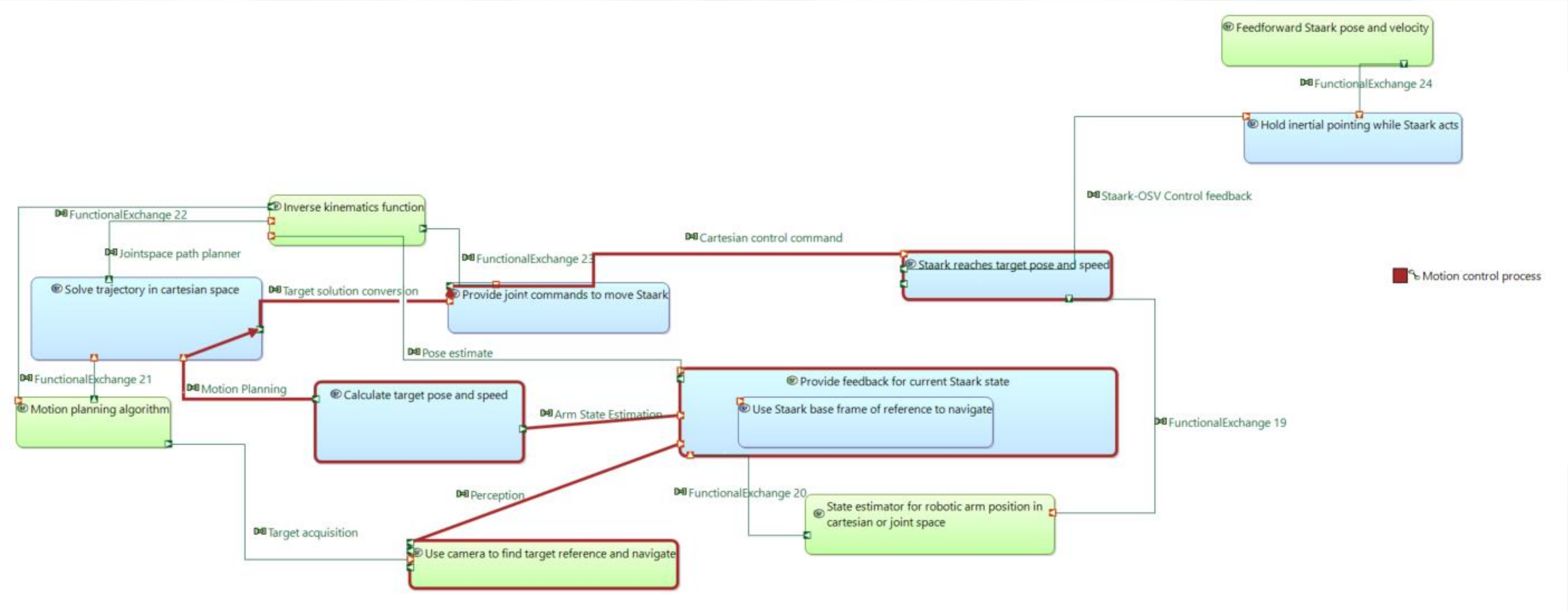


Mission-Capability

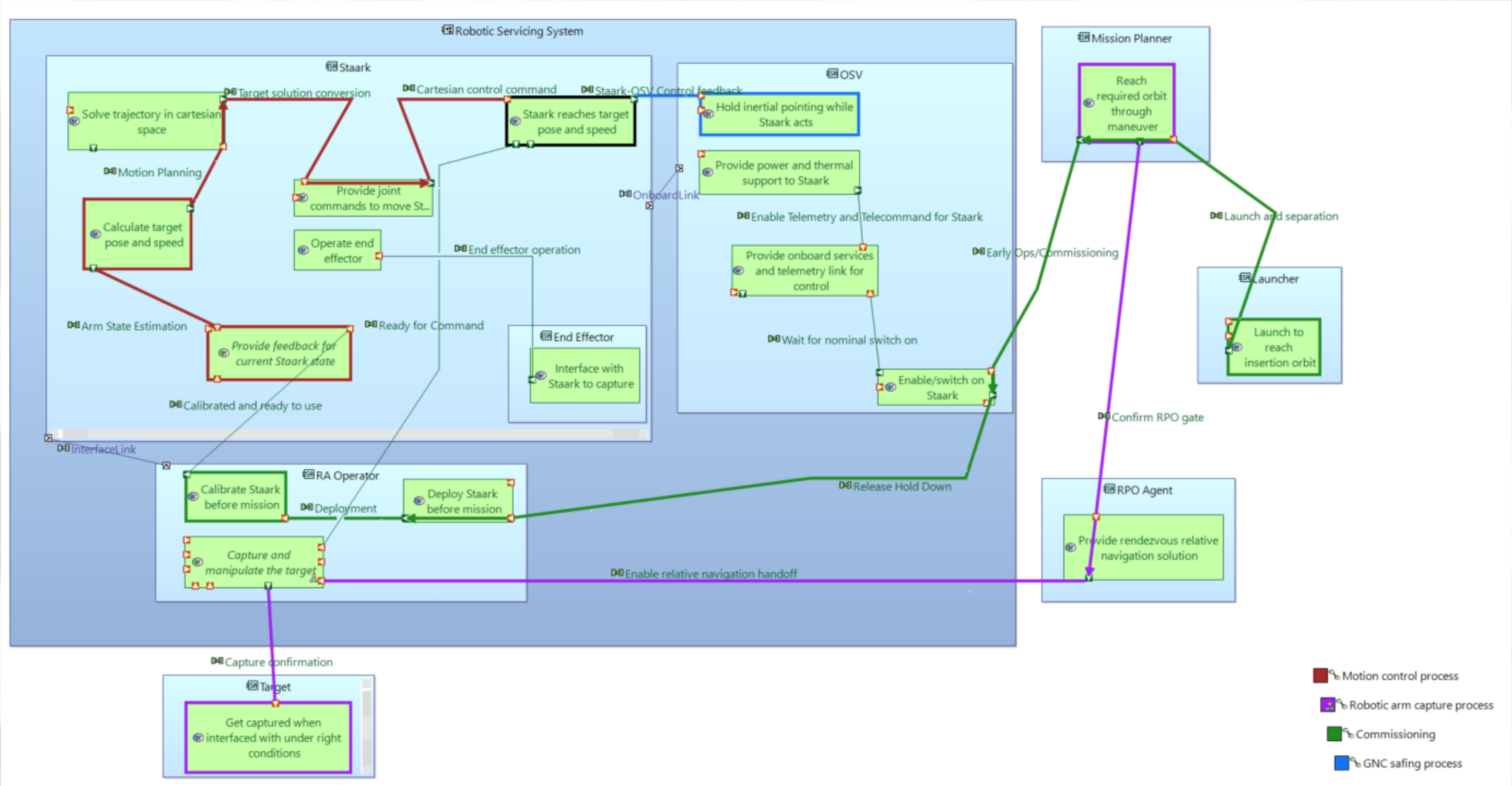
- Primary mission involves
  - Surviving the launch
  - Providing services to Staark
  - Reaching target through orbital maneuvers
  - Providing required RPO performance
  - Deploying robotic arm, commissioning
  - Capturing and manipulating target



Development of system functions



Architecture for system analysis



Robotic Specification Framework

R1-S0 Taxonomy

Robotic Taxonomy

R1-S1 Communication

Interfaces

R1-S2 Perception

Sensing

R1-S3 Planning

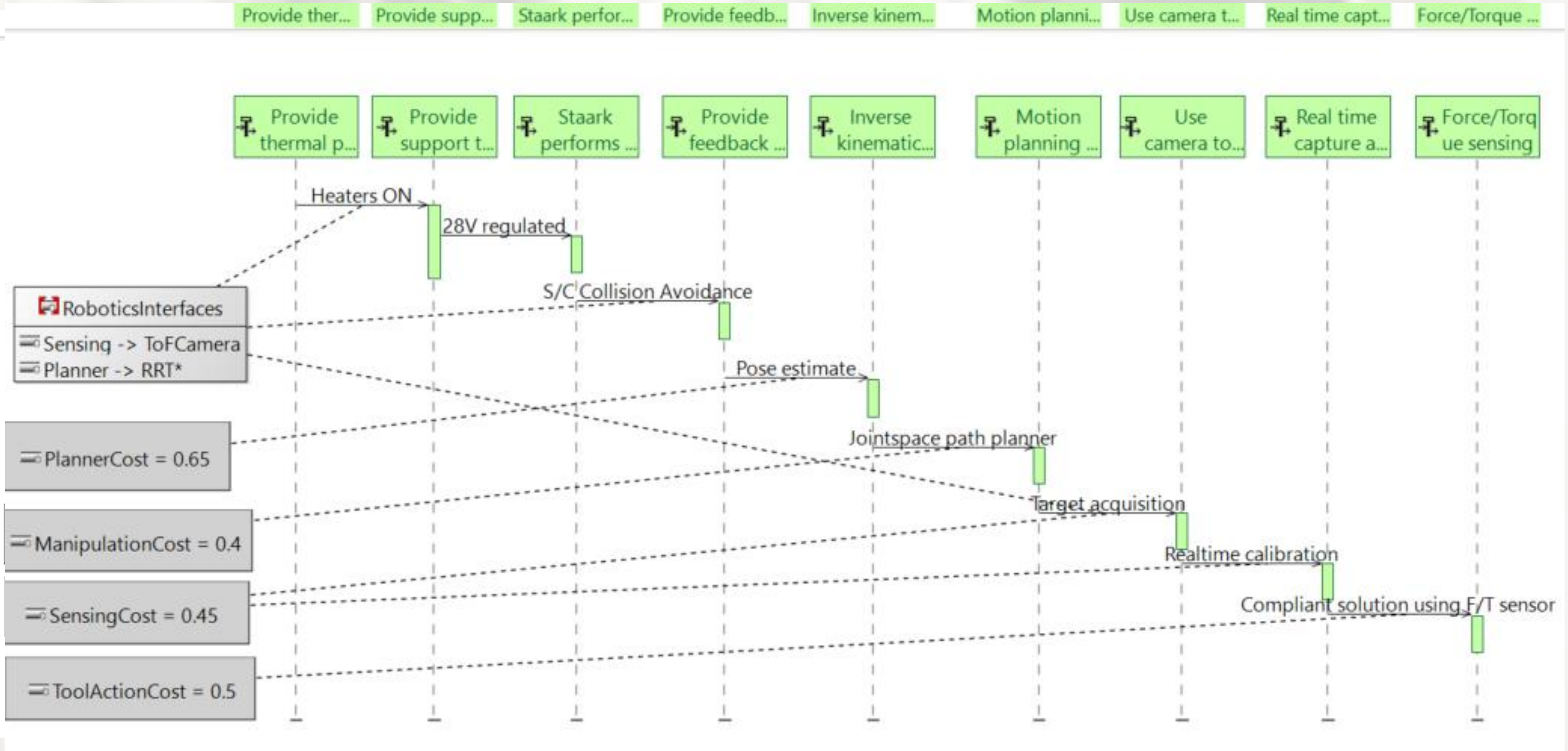
Motion Planning

A normalized cost can be prescribed on the last 2 layers to arrive at a robotic cost for the mission.

Cost = C(Sensing) + C(Motion Planning) on each robotic task

PVMT Assignment

- A score is assigned based on the difficulty of the task for the robotic architecture
- A quantitative tradeoff is thus achieved on summing the full score



$Cost_{Scenario1}(total)=1.5$; $Cost_{Scenario2}(total)=2$

Conclusion

- Capella helped in reducing modeling effort for Staark robotic application case studies
- Capella helped most in architecture analysis, reduced effort by upto 60% versus traditional methods like NAF
- Capella also helped share SoS like frameworks when required
- MBSE in robotic architecture and system definition plays a key role for orbital servicing missions

Special thanks to **Obeo**, **Thales** and **Redwire Space Europe** for making this talk possible